A STUDY OF THE FATE OF FERTILIZER NITROGEN IN SOIL

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SUMMARY

1. Fertilizer NO_3-N was applied to fallow and planted soil. In a field experiment the rates of application in factorial combinations were 30 and 60 kg NO_3-N/ha in the autumn (December) and 60 and 90 kg NO_3-N/ha in the spring (May). Samples of soil cores down to 60 cm., and plant material (winter wheat) were taken periodically throughout the December to September growing season.

Greenhouse experiments were carried out using topsoil and subsoil separately. In the first greenhouse experiment, 45 cm. columns of topsoil and of subsoil were used under plant (rye grass) and fallow with and without 60 kg NO_3-N/ha. Duration was 7 weeks. Three watering regimes were applied, i.e. 60, 90, and 120 percent of the water holding capacity. The excess water from the highest water regime was collected. The second experiment was carried out on topsoil only. Soil was ignited to destroy organic matter and was compared with the unignited soil under fallow and planted (rye grass) receiving NO_3-N at rates of 25 and 50 ppm.

A laboratory experiment was carried out investigating the effect of two aggregate sizes (1-3 and 3-6 mm. in diameter) on leaching losses of added NO_3-N.

2. Soil samples were analysed for NO_3-N and NH_4-N in 4 horizons from the field experiment (3 from the Greenhouse Experiment I) each 15 cm deep, and from each of the Greenhouse Experiment II and the laboratory experiment. Leachates were analysed for the same two mineral fractions of nitrogen. Plant samples were analysed for total N.

3. The field experiment showed that the number of soil cores is a limiting factor and better results could be obtained only by taking more replicates.

4. Recovery of fertilizer N at the end of the season ranged from 67-77% in the field experiment (9 months) and from 60-95% in the greenhouse experiments (nearly 2 months) under conditions of no leaching. However, when leaching was excessive, recovery of fertilizer N was as low as 2%.

5. Leaching losses of fertilizer N could be as high as 100%. Movement of fertilizer N occurred within 3 weeks of application, translocating fertilizer N from the surface to 45-60 cm deep in soil. Precipitations ranging from 38 to 1025 mm resulted in downward translocation of fertilizer N. The size of soil aggregates showed their important role in holding fertilizer against loss by leaching. Planted soils lost about 30% by leaching; fallow ones lost more than 75% within 3 weeks under 482 mm precipitation.

6. The topsoil possessed greater capacity for mineralization and immobilization than the subsoil. This was proved by experiments comparing behaviour of fertilizer N in topsoil vs. subsoil and in ignited vs. unignited topsoil.

7. The proportion of fertilizer N immobilized was greater in the fallow (about 90%) than in the planted. Indications of remineralization were shown in both field and greenhouse experiments.

8. Denitrification and reduction of NO_3-N was shown in both topsoil and subsoil and in the ignited topsoil. Fertilizer NO_3-N moving from topsoil down to the subsoil - under field conditions - seems to have been reduced to elemental N rapidly in the subsoil.

9. There are indications that application of fertilizer enhances mineralization immediately (up to 3 weeks) after application; but within 3-4 months it seems that fertilizer enhances immobilization. Exudation of fertilizer N by plants may have had an important effect on its status in soil.

I INTRODUCTION

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Nitrogenous fertilizers are applied to most crops mainly as soluble chemical compounds in which the nitrogen exists as either NO_3 or NH_4 or both. Nitrate nitrogen is completely soluble in the soil moisture but is not held by the soil colloids. The ammonium form is also soluble but it is capable of being held as an exchangeable cation on the surface of soil colloidal particles.

The purpose of applying fertilizer nitrogen is to stimulate plant growth and increase yields. Therefore a large recovery by crops of applied nitrogen is usually beneficial. Unfortunately, part of the fertilizer nitrogen fails to appear in crops. Cooke (1964) reported that a recovery of 50% or thereabouts is a commonplace in practical agriculture. Part of the remainder leaves the soil-plant system altogether as volatile and/or soluble compounds. The other part remains in the soil in forms which are unavailable to plants.

A better understanding of the factors affecting the processes that added fertilizer nitrogen undergoes would be of great value in making the most efficient use of nitrogenous fertilizers in agriculture.

A great deal of work has been and is still being done on the different types of transformation which take place from the time fertilizer nitrogen is applied to soil. Techniques using N^{15} and conventional techniques with N^{14} are used in those studies. Methods using growth cabinets with closed-systems and others using leaching techniques are also employed. Field, greenhouse, and

laboratory investigations complement each other and throw more light on the behaviour of fertilizer nitrogen in soils, with resulting improvements in utilisation by plants of this valuable nutrient.

II REVIEW OF LITERATURE

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PATHWAYS OF FERTILIZER NITROGEN

The main routes or pathways which fertilizer nitrogen can take are as follows:

1. Loss from soil-plant system:
   a) By leaching in drainage water, and flowing in rivers to lochs and oceans
   b) By volatilization and denitrification.
2. Removal by the crop:
   Uptake by growing crops, the major part of which is taken off the farm.
3. Conversion to less readily available forms within the soil:
   a) Direct conversion into organic forms as a result of assimilation by soil micro-organisms. This process is referred to as immobilization.
   b) Trapping of NH_4-N in clay minerals cavities resulting in at least temporary unavailability for either plants or microflora. This process is referred to as 'ammonium fixation'.

It is the proportion of nitrogen taking the 'plant uptake' pathway which soil and plant nutrition scientists seek to increase.

LEACHING OF FERTILIZER NITROGEN

Following an application of a nitrogenous fertilizer, nitrogen would gradually come into solution and move within the soil profile.

The downward movement has been investigated by research workers in 3 ways. Firstly by measuring the NO_3-N or $(NO_3 + NH_4)$-N content in different horizons and secondly by measuring the concentration of nitrogen in soil solution and thirdly by measuring the amount of nitrogen lost in the drainage water. McAllister (1967a and b) studied the content of NO_3-N in the surface 0-5 and 5-10 cm of the soil and reported that fertilized soil maintained a higher content than unfertilized soil for as long as 6 months following fertilizer application. After $3\frac{1}{2}$ months of N application the top 5 cm. of bare fertilized soil contained 52 and 114 ppm NO_3-N (for soil fertilized by $NaNO_3$ and $(NH_4)_2SO$ respectively) compared with 27 ppm in the unfertilized soil (McAllister 1967a); in the 5-10 cm layer of soil there also was a higher content of nitrate in fertilized plots as compared to unfertilized ones. (McAllister, 1967b). Gasser (1961) determining NO_3^- and NH_4^- in the top 15 cm of the soil throughout a winter wheat season reported that the main factor affecting nitrogen movement is the quantity of rainfall. All the autumn applied nitrogen had moved from the surface 15 cm to the underlying horizons during the winter. When nitrogen was applied in the spring, there was a substantial proportion of fertilizer nitrogen still in the surface 3 months following application. Cunningham and Cooke (1958) measured mineral nitrogen in soil in two adjacent horizons 0-22·5 and 22·5-45 cm and stated that there was a slow downward movement under the effect of rain; and that only heavy and prolonged rainfall would give rise to an appreciable downward movement of fertilizer nitrogen. Examining the soil

profile in 15 cm. thick horizons, Shaw (1962) showed that with 40 cm of rain, there was 40% of the added NO_3-N in the 30-45 cm horizons 6 months following application. Gasser (1962) reported that during the 4 months of winter leaching could take as much as 80% of the added fertilizer nitrogen below 90 cm Nommik (1966a) examined the soil down to 100 cm and reported the downward movement of fertilizer nitrogen in solution resulting in the accumulation of nitrogen in the deeper 60-80 and 80-100 cm horizons. Applying artificial rainfall, van der Paauw (1968) found 77 kg N/ha in the surface 50 cm soil following 20 cm of rain, but less than half the amount (29 Kg N/ha) following 54 cm rain.

A method for the direct measurement of nitrogen in the soil solution at different depths was described by Wagner (1962) who later reported (Wagner 1965) a considerable movement of fertilizer nitrogen down to 90 cm Four months after the application of 450 kg N/ha to the soil surface, 170 Kg N/ha had removed to the 60-90 cm horizon and only 57 Kg remained in the top 30 cm. He arrived at the same conclusion as Nommik (1966a)and Shaw (1962) that there was a movement of fertilizer nitrogen to deeper horizons and ultimate loss from the soil profile by leaching. In a laboratory experiment, Bates and Tisdale (1957) reported similar results; they showed that the addition of water caused a build-up of mineral nitrogen in the lower segments of soil columns but a decrease in the upper. Nommik (1966a) attached appreciable importance to the role of water holding capacity of soils in retaining fertilizer nitrogen. He stated that the high water

holding capacity of a heavy soil contributed to the high retention of fertilizer nitrogen ($Ca(NO_3)_2$ and $(NH_4)_2SO_4$) as compared with the low retention in a light one. Shaw (1952) on the other hand, discussing the higher rate of N movement in some heavy soils, compared with the relatively slower rate in the light soils, concluded that this was due to the vertical cracks in the heavy soil. He concluded that nitrate was distributed throughout the profile of light soils but that in heavy soils most of the applied nitrogen disappeared from the top 60 cm. through the structural fissures. Gasser (1961, 1962) found something similar. Although the soil in his investigation was a light one, the soluble mineral nitrogen was not entirely leached despite heavy rainfall.

The amount of nitrogen leached from a soil profile under field conditions can be measured by the use of lysimeters. Allison et al. (1959) reported losses of fertilizer nitrogen by leaching in lysimeters of from 34% to as high as 100% of that applied in fertilizer. Various workers on the other hand, quoted values ranging from as low as 3% to 40% (Kolenbrander, 1969; Owens, 1960; Pratt et al., 1967; Takahashi, 1968; Zamyatina et al., 1968). It is worth mentioning that the deep lysimeters (150-170 cm.) of Pratt et al. (1967) and Zamyatina et al. (1968) are where very little loss was reported, but losses from the shallower lysimeters (45 cm.) of Overrein (1969) were as high as 92%.

On soils of heavy texture, Kolenbrander (1969) reported little leaching of nitrogen. In soils with 35% or more clay, leaching losses were in some cases as small as 3·3%. One reason suggested

for this small loss by leaching was that the NO_3-N was already being removed by another route e.g. denitrification. On lighter soils (0-10% clay) on the other hand, losses by leaching could be as high as 20% of that applied. Zamyatina et al. (1968) reported very little (1%) loss by leaching from two podzolic soils during a full oats season. In an experiment carried out by Owens (1960) the leaching losses varied from 5-20% after 2 years corn; the amount lost was proportional to the amount of water percolating through the lysimeter. Similar findings were reported by Kolenbrander (1969). He reported that higher losses (40%) were associated with winter-applied nitrogen which was subject to more rain than with spring applied nitrogen. The effect of plant cover on nitrogen leaching was demonstrated by lysimeter studies (Allison et al., 1959; Karraker et al., 1950; Kolenbrander, 1969). Loss by leaching from fallow soil amounted to 74% while with a plant cover it ranged from 15-58% (Karraker et al., 1950).

Lysimeters allow factors affecting the movement of fertilizer nitrogen through the soil profile to be studied under as near field condition as possible, but unfortunately, there are a number of shortcomings associated with the technique; these are as follows:-

1. An undisturbed soil profile (a monolith type of lysimeter) would provide data applicable to field conditions but unfortunately this type of lysimeter is very difficult to construct. Most lysimeters are therefore of the "filled in" type where the soil system is greatly different to field conditions.

2. The absence of a natural water table: The existence of a water table allows continuity of water through part of the profile at least but where there is no water table the contact between the soil phase and the liquid phase is broken. Separation of the two phases is bound to break the dynamic chemical-solid-liquid equilibrium which operates under natural conditions. Also the upward movement of soil moisture does not operate in the lysimeter system. A third factor arising from the separation of the two phases is the change in moisture content in the lower part of lysimeter: Colman (1946) reported that the absence of natural water table in lysimeters gives rise to greater moisture retention.

Despite these shortcomings, the lysimeter serves as a useful tool, demonstrating the effects of different factors on the movement of nitrogen and also on the status of other nutrients. The technique can also be used in nitrogen-balance studies in as near natural conditions as possible (Overrien, 1969).

TRANSFORMATION OF FERTILIZER NITROGEN TO GASEOUS FORMS

Transformation of fertilizer N into gaseous forms (ammonia, nitrogen and oxides of nitrogen) is likely to take place in the soil under natural conditions. The process by which NH_3 is evolved is referred to as "loss by volatilization" and the one that results in the release of elemental N or its oxides is called 'denitrification'.

Ammonia Volatilization

A nitrogenous fertilizer containing ammonium, ammonia, or materials such as urea which releases NH_3 fairly easily in soil, may lose some nitrogen by the formation and subsequent volatilization of ammonia gas to the atmosphere. This is most likely to happen in alkaline and calcareous soils. In alkaline soils, the dominant OH^- ions would form NH_4OH by reacting with ammonium compounds and by hydrolysis and dissociation of that compound NH_3 is likely to volatilize from soil moisture (Wahhab et al., 1957). With higher content of calcareous materials in the soil, NH_3 is evolved as a result of the disintegration of the unstable $(NH_4)_2CO_3$ (Terman et al., 1968). Ammonia can be evolved even from acid soils after the addition of fertilizer (Wagner and Smith, 1958; DuPlessis and Krootje, 1964; Blasco and Cornfield, 1966) if the acid soils contain sufficient basic minerals. Blasco and Cornfield (1966) noted that the loss by volatilization varied from 6 to 12% in six acid soils (pH ranging from 4·8 - 5·6) and the one with the highest NH_3 volatilization contained the highest content of 'basic' minerals. On the other hand Martin and Ross (1968) reported negligible losses (0·6%) from an acid soil (pH 5·7). Increasing soil pH increases losses by volatilization. Loftis and Scarbrook (1969) obtained an increase of 9% in the amount of volatilized ammonia after liming, and DuPlessis and Kroontje (1964) reported a twenty-fold increase. At pH 4·5 the loss was 0·15 ppm but became 6·00 ppm when pH was increased to 7·1.

The risk of loss by volatilization is greater in soils with a low cation exchange capacity (C.E.C.). The higher the C.E.C. the more room there is for NH_4^+ and NH_3 to be adsorbed on the surface of the colloidal particles. Consequently, it is easier for NH_4 to volatilize from soils with a low cation exchange capacity (Acquaye and Cunningham, 1965). Loftis and Scarbrook (1969) showed that with a C.E.C. of 3·7 me/100 g loss by volatilization amounted to 19%; a smaller loss (13%) was reported from a soil with a higher (13 me/100 g) C.E.C.; and there was almost no evolution from a soil of 33 me/100 g. Increase in temperature increases the rate of volatilization (Wahhab et al., 1957; Ernst and Massey, 1960). An increase in moisture content up to 25% of the W.H.C. also increases the loss but above this level there is a decrease in the amount evolved (Wahhab et al., 1957; Acquaye and Cunningham, 1965).

While the loss of NH_3 by volatilisation can be greater from NH_4-N very little loss takes place from nitrate N (Broadbent and Nakashima, 1968; Nommik, 1966(b); Musa, 1968).

The loss by volatilization increases with the rate of application. Loftis and Scarbrook (1969) reported 2% loss with an application rate of 112 kg N/ha which increased to 9% and 16% when the rates were 224 and 336 kg N/ha respectively. Wahhab et al. (1957) reported a loss of 15% and 7% at a rate of 250 ppm rising to 25% at 1000 ppm. The rate of volatilization was found by Harding et al. (1963) to increase immediately after application, and decrease with time. It was 0·46 kg N/ha/h during the first 6 hours following application and decreased to 0·07 kg N/ha/h after 6 days.

To keep the loss of NH_3 to the atmosphere to a minimum it is recommended that fertilizer materials containing ammonia or ammonium, as well as those which produce ammonia, should be thoroughly incorporated in the soil (Acquaye and Cunningham, 1965; Nommik, 1966(b); Musa, 1968). Oganov and Ibragimov (1966) recommended addition of $CaHPO_4$ which decreases loss by volatilization from $(NH_4)_2SO_4$.

Denitrification

While the loss of ammonia by volatilization is more likely to happen to NH_4^+ compounds, the loss by denitrification occurs to nitrate and nitrite forms. The process is one of reduction of nitrate(NO_3^-) to N and/or the oxidized volatile forms (Broadbent and Clark, 1965). The process is mainly biological through soil micro-organisms. However, there is a partly chemical partly biological process, referred to as chemo-dinitrification in which NO_3^- is reduced to N and/or the oxidized volatile forms (Clark, 1962).

(i) Biological denitrification

When the supply of oxygen in the soil becomes limiting, certain micro-organisms have the ability to use nitrate or nitrite ions instead of oxygen as the electron acceptor (Broadbent and Clark, 1965; Woldendrop, 1963). Valera and Alexander (1961) reviewed the different groups of denitrifying bacteria and their environmental requirement. Nason (1962) defined two categories of reduction.

a) assimilatory reduction by which nitrate is reduced to ammonia or amino acid both of which are used for the bio-synthesis of cell constituents

b) dissimilatory reduction or nitrate respiration in which NO_3- is used as terminal electron acceptor in place of oxygen. Products in this case include nitric oxide, nitrous oxide and molecular nitrogen. Thus this dissimilatory reduction of nitrate is strictly speaking a 'biological denitrification'.

There are two main factors influencing the extent of this type of denitrification namely the degree of O_2 deficiency and the presence of energy-supply material. Simpson (1960) found that nitrate accumulation took place in the field during the 'drying-out' of soil after rain when aeration, moisture and temperature were favourable for nitrification and the retention of nitrate ions. This worker also found that a sudden downpour after a dry period produced anaerobic conditions, and that these resulted in the loss of recently formed nitrate by denitrification. Greenwood's equations (1963) confirm and explain Simpson's findings and, in addition, may explain why the nitrogen fertilizer requirements of the drier counties of Britain are greater than in the wetter counties.

Greenland (1962), in his laboratory investigation on wet soil at different moisture contents showed that at moisture content equivalent to 70% of W.H.C. 20% of added nitrate was denitrified and at 160% W.H.C., 97% of added nitrogen was denitrified. Bremner and Shaw (1958) reported similar results; 5 - 54% and 6 - 100% of added nitrate were denitrified at 60% and 120% of W.H.C. The addition of energy-supplying material resulted in an increase in the proportion of fertilizer nitrogen denitrified (Bremner and Shaw, 1958; Greenland, 1962). Jansson and Clark (1952) found that peptone gave rise to more denitrification than glucose. Skyring (1962) attributed the persistence of a high concentration of nitrate at 75 cm. depth in a Black Earth where the environmental conditions favoured denitrification to the lack of easily decomposible energy material.

(ii) Chemo-denitrification.

Chemo-denitrification takes place in two stages. The first is operated by micro-organisms which reduce NO_3- to NO_2-. The second is entirely chemical in which nitrite reacts with compounds

such as α-amino acids or ammonium compounds to give elemental nitrogen or an unstable compound which dissociates into nitrogen and its gaseous oxides. Studying the reduction of nitrite to nitrogen in a sterile soil, Bulla *et al*. (1968) reported a non-enzymatic (i.e. non-biological) reduction of nitrite ion evolving nitric oxide as well as nitrogen gas. Allison (1963) cited the three possible reactions in which nitrite is evolved as follows:-

(1) Chemical decomposition of nitrous acid

$$3HNO_2 \longrightarrow 2NO + HNO_3 + H_2O$$

(2) Reaction of the Van Slyke type where nitrous acid reacts with α-amino acids, and to a lesser extent with other compounds such as urea, pyrimidines, methylamine, purines

$$RNH_2 + HNO_2 \longrightarrow ROH + H_2O + N_2$$

(3) Formation and decomposition of ammonium nitrite

$$NH_3 + HNO_2 \longrightarrow NH_4NO_2 \longrightarrow N_2 + 2H_2O$$

The first and second reactions were found to proceed only in acid soils of pH below 5·0 - 6·0 (Allison and Doetsch, 1951; Allison *et al*. 1952; Gerretsen and DeHoop, 1957). Because of this and because of the slow rate at which these two reactions proceed, Allison (1963) considered the third reaction to be the most important as it occurs in a wider range of soil pH reaching, pH 10. However Woldendorp (1968) in his review of gaseous losses of nitrogen from nitrite did not share this opinion and concluded that there were mechanisms involving metallic cations and some organic material. In his opinion more information is needed before assessing the relative importance of the mechanisms involved.

The combined (nitrate → nitrite → N) mechanisms are frequently referred to as denitrification from the practical point-of-view. Carter et al. (1967) and Walker et al. (1956) attributed the low recovery of nitrate, compared with ammonium, to denitrification. The 6 - 30% deficit reported in the NO_3 nitrogen balance studies (McVicar et al., 1951; Owens, 1960; Legg and Allison, 1967) was also attributed to denitrification. Even in well aerated soils, Broadbent and Stojanovic (1952) reported some denitrification. However, under normal field conditions and in well aerated soils, denitrification is of very little importance (Greenland, 1962; Overrein, 1969).

IMMOBILIZATION

Part of fertilizer nitrogen is assimilated by the soil microflora as cell protoplasm. This locking-up is referred to as 'immobilization' of fertilizer nitrogen. It is widely reported (Andreeva and Scheglova, 1966; Broadbent, 1966; Jansson, 1958) that micro-organisms prefer ammonium to nitrate nitrogen for tissue synthesis. This is one of the reasons for a higher immobilization of NH_4 than NO_3 fertilizers. Organic matter affects the rate and extent of immobilization. Fresh organic plant residues incorporated in the soil increase the rate and extent of immobilization (Hiltbold et al., 1950; Bartholomew and Hiltbold, 1952; Stojanovic and Broadbent, 1956; Terman and Brown, 1968). An organic material with a wide C/N ratio (i.e. an energy supply material) would increase immobilization whereas a narrow C/N organic material would even

encourage mineralization.

Hiltbold et al. (1950) demonstrated that all fertilizer nitrogen was immobilized when an energy-supply material such as cornstalk was incorporated in the soil. Smirnov et al. (1967) reported similar results with wheat straw. Harmsen and Van Schreven (1955) reported that when the C/N ratio is 20 - 25 or wider (i.e. when N% in organic residues is 1·5 - 2·0% or lower) a net immobilization of fertilizer nitrogen begins to take place. Picci (1959) reported that substances which are easily ammonified like casein and peptone resulted in a depletion of fertilizer nitrogen. Bartholomew and Hiltbold (1952) recorded a duration of a net immobilization of 37 - 73 days when there was an abundant amount of plant (oats) residues in the soil. Of particular interest is the study carried out by Smith (1967) who investigated the effect of two energy sources on the status of mineral nitrogen in the soil. A decomposing layer of plant material of low (below 1·3%) nitrogen content caused a diffusion of soil NO_3 into the layer, presumably to meet the high demand by micro-organisms for N but the material with higher (2·1%) N content released NH_4-N from the decomposing layer to the soil.

Chu and Knowles (1966) studied the forms of organic-N to which fertilizer N is transformed following 100 days of incubation. They found that 50 - 60% of the fertilizer nitrogen was immobilized in the amino acid fraction but only 13% of added fertilizer nitrogen was in the highly insoluble humin fraction.

The problem of immobilization of nitrogen is very important in practical agriculture because of its effect on the residual values

of fertilizer nitrogen. Clement (1968) and Collier (1968) found no residual fertilizer nitrogen in the second year. Koritskaya (1968) found that although there was as much as 45% of fertilizer nitrogen remaining in the soil one year following application, only 2 - 7% was available for plants. Zamyatina et al. (1968) reported similar results following one season in cereals, 1% of fertilizer nitrogen was in mineral form while 30-40% was in organic form.

FIXATION OF FERTILIZER NITROGEN

Part of the fertilizer nitrogen, applied as ammonium is held in the cavities of some soil minerals and rendered inaccessible to plant roots and micro-organisms; this process is referred to as fixation (Nommik, 1965). The deeper soil horizons fix more nitrogen than the upper (Young and Cattani, 1962) and the higher the clay content, the greater the proportion of ammonium fixed (Mogilevkina, 1965). McDowell and Smith (1958) found that 6.1% was fixed by a sandy loam and 27% by a clay. The capacity of clay minerals to fix ammonium varies, illite was reported to fix more than montmorillonite (Stevenson and Dhariwal, 1959) and vermiculite more than montmorillonite (Young and McNeal, 1964).

McDonnell et al. (1959) found that considerable quantities of fixed ammonium were released after prolonged ball milling (between 100 and 500 hours) of soils suspected of containing fixed ammonium. The amounts released were proportional to the time of milling, and dry milling was more effective than wet grinding.

There is evidence, however, that part of the fixed ammonium is available to nitrifying micro-organisms, 37% of NH_4 fixed by soil minerals was available to nitrifiers (Allison and Roller, 1955). Fixation of ammonium was reported to occur even in some primary silica minerals (Adams and Stevenson, 1964).

An increase in organic matter content seems to increase the amount of ammonium fixed by soil (Sohn and Peech, 1958; Young, 1964).

EFFECT OF PLANT COVER

There are several ways in which a plant cover can influence the amount of fertilizer nitrogen in the soil.

(1) Uptake of fertilizer nitrogen:

Uptake of fertilizer nitrogen by plants means a conservation of fertilizer nutrients and a protection against loss by leaching and other mechanisms.

(2) Movement of water through the soil profile:

The presence of growing plants increases the rate of evapotranspiration and reduces the downward flow of water into the drains. This would decrease the loss of nutrients to the drainage water.

McAllister (1967a) reported a more rapid downward movement of applied NO_3-N on grassland than on fallow ground, when the fertilizer was applied before the commencement of vigorous growth. This effect could be due to the presence of channels in the grassland created by decayed roots. During active growth, however, there was a smaller loss by leaching from the grassland than from the fallow ground.

(3) Content of oxygen in soil air:

Since living plant roots use oxygen for respiration, its concentration in the soil air would decrease. This, under certain conditions when replacement of the oxygen from the atmosphere becomes difficult, could affect biological activities and ultimately nitrogen in the soil.

(4) Excretion of organic materials such as amino acids by plant roots would influence soil microbial activities and have a bearing on nitrogen transformations in the soil.

The first two factors, i.e. uptake of fertilizer nitrogen and a retardation of the downward movement of nitrogen seem to favour a conservation of fertilizer nitrogen. The third factor is unfavourable and the last is controversial. The net result of these four factors represents the ultimate effect of plant on fertilizer nitrogen.

Effect of Plant Uptake of N:

The uptake by the plant of fertilizer nitrogen is an important factor in conserving nitrogen. Theoretically if the plant were to remove all fertilizer nitrogen, there would be little opportunity for the other processes to operate. Practically and unfortunately total recovery of fertilizer N is never realised. However, a number of workers have managed to obtain recoveries approaching 100% (Thornton, 1946; Gasser and Iordanou, 1967; Legg and Allison, 1967; Andreeva and Scheglova, 1968). These high recoveries come from a number of isolated cases in their work. The 98% recovery by Thornton (1946) was the result of removing 4·9 mg. of fertilizer nitrogen out of 5 mg. added but the amount recovered represents only a small (2·8%) fraction of the total N in the plant. The 98% recovery reported by Gasser and Iordanou (1967) was recorded 80 days after application, but at harvest, the recovery fell to 59%. The 85% recovery reported by Legg and Allison (1967) was achieved in three successive crops over 20 weeks and nitrogen was determined in both tops and roots of plants. Andreeva and Scheglova (1968) reported 85% recovery in one case. This demonstrates the remarkable effect of plant on the preservation of fertilizer nitrogen.

Effect due to Movement of Water through Soil Profile:

There is ample evidence (Woldendorp et al., 1965; Bavel et al., 1968) that the presence of growing plants exerts a conserving effect on soil nutrients by transferring water from the soil to the atmosphere. This lessens the amount of soil solution lost to the drains and encourages an upward movement of nutrients in the soil solution making them accessible to plant roots. Woldendorp et al. (1965) concluded that the upward movement of water in the soil during the spring and summer enabled grass to remove nitrogen which would otherwise have been lost by leaching. Water (Kolenbrander, 1969) and nitrogen (Salam, 1968) lost by leaching from uncropped soil were higher than from cropped soil. Smirnov et al. (1968) reported a remarkable effect of plant cover on retaining fertilizer nitrogen against leaching. They reported a 60% loss in fallow soil against 10% in cropped. Similar results were reported by Takahashi (1968). Bavel et al. (1968) showed that evapotranspiration was greater in cropped soil as compared with fallow, and this would have a favourable effect on plant nutrients rendering them accessible to plant roots.

Change in Oxygen Content in Soil.

An increase in the number of plant roots in the soil increases the consumption of oxygen in the rhizosphere. Woldendorp (1963) reported the consumption of oxygen in the rhizosphere to be 27 times that in the unplanted soil. The higher consumption of oxygen in the rhizosphere results from 2 causes: firstly the activity of plant

roots themselves and secondly the activity of the soil micro-organisms which are more active in the presence of living roots (Katznelson and Bose, 1959). According to Woldendorp (1963), living roots consume 57% of oxygen leaving 33% to micro-organisms. It follows that, under certain circumstances, where a grassland of a heavy soil texture in a wet climatic condition giving rise to a retardation of adequate ventilation in the rhizosphere would encourage a process like denitrification and thus losing a proportion of fertilizer nitrogen (Woldendorp, 1963).

Excretion of Organic Materials by Plant Roots:

Plants have been shown to excrete materials through their roots during the course of their life (Rovira, 1956, 1959, 1965; Ayres and Thornton, 1968; Vancura, 1964). Quantitative as well as qualitative differences in root exudates are reported between different plant species. Rovira (1956) reported that about 40 µg. of sugars per plant were excreted by oats and a similar amount by wheat during the first 10 days of growth. Vancura (1964) reported that a single plant in its first 10 days of cultivation in sterile sand liberates from its seed and releases from its roots 0·4 - 0·5 mg. of excreted material into its surroundings. The dry matter of the excretion from a barley plant contained 9% reducing substances 19% ash 18% volatile and non-volatile acids and 1% nitrogen, two thirds of which is in the form of amino acids. He reported that wheat plant gave similar results. Rovira (1965) reported marked variety in the compounds excreted by plant roots and that oats excreted smaller quantities than peas. The

highest amount of tomato plant exudates took place during the first 2 weeks following sowing.

These plant excretions have a bearing on the availability of fertilizer nitrogen in the soil/plant system. The excretion of nitrogen in the form of amino acids represents a loss of nitrogen from the plant, and a step towards immobilization of fertilizer nitrogen. The low recovery (59%) obtained at harvest of oats by Gasser and Iordanou (1967) after a 98% recovery during the season (80 days after sowing) was attributed to plant excretion of nitrogen during the season. It was found by Woldendorp et al. (1965) that ryegrass excreted 10% of its nitrogen to the soil during 3 weeks in June. The other way by which plant excretion affects fertilizer nitrogen in the soil-plant system is an indirect one; i.e. the effect on micro-organisms. A supply of easily utilisable materials is bound to increase the activity of soil micro-organisms. This is confirmed by work of a number of research workers who reported an increase in both activity and number of micro-organisms in planted soils compared with fallow (Katznelson and Bose, 1959; Goring and Clark, 1949; Bartholomew and Clark, 1950). Consequently, in the presence of easily utilisable nitrogen (including added fertilizer nitrogen) there is a chance of a greater immobilization of soluble nitrogen in planted soil in comparison with fallow. Results published by Hiltbold et al. (1950), Goring and Clark (1949); Smirnov (1968) and Bartholomew and Clark (1950) confirm this contention. A greater immobilization of added fertilizer nitrogen took place in planted soil as compared with unplanted ones. Furthermore, Bartholomew

and Clark (1950) demonstrated that by the addition of energy material (Cornstalk), immobilization was accentuated in a planted soil in comparison with a fallow one.

However, other workers reported that most of these exudates occur during a few weeks at the beginning of the crop season. Smirnov et al. (1968) reported that immobilization in planted soil exceeded that in the unplanted during the first 2 weeks; and Bartholomew and Hiltbold (1952) reported a duration of 5 weeks after sowing. This is in agreement with Rovira's reports (Rovira, 1956; 1959) which showed that the highest rate of plant excretion (of tomatoes, subterranean clover, phalaris) occurred during the first 2 weeks of growth.

III METHODS AND MATERIALS

(1) FIELD WORK

DESCRIPTION AND DETAILS OF

A. FIELD EXPERIMENT: 1968 - 1969

B. GREENHOUSE EXPERIMENT I: Losses of fertilizer N in soil columns.

C. GREENHOUSE EXPERIMENT II: Effect of soil organic matter on the availability of fertilizer nitrogen

D. LABORATORY EXPERIMENT: Effect of aggregate size on leaching loss of NO_3-N.

(A) FIELD EXPERIMENT 1968-69.

"Effect of fertilizer N on fallow and planted systems".

The purpose of this experiment was to study the behaviour of added nitrate nitrogen in soil under field conditions with and without plant cover. Estimation of the movement of ammonium and nitrate nitrogen in soil down to 60 cm in addition to plant (winter wheat) uptake of N throughout the growing season would help in the understanding of the fate of fertilizer nitrogen added to the soil.

SOIL:

The experiment was carried out at Niddry Mains Farm, Winchburgh, Midlothian. The field surface was level and with free drainage. A typical soil profile down to 75 cm is shown in Plate 1. The surface soil to a depth of 30 cm is dark grey due to organic matter accumulation whereas the underlying horizons are light brown to yellowish and have a lower organic matter content. Table 1 shows the soil mechanical analysis, pH, and cation exchange capacity of different horizons.

The field was under wheat for the 5 years preceding the 1968-1969 season and supplied only with mineral fertilizers (including NH_4NO_3) with no application of farmyard manure. The annual rate of nitrogen application during these years was approximately 30 kg N/ha. The usual practise of disposing of straw and stubble was by burning. Therefore the complication of fertilizer nitrogen interchange with soil organic matter is kept to minimum.

Plate 1: Field Experiment

Profile of the soil

Table 1: Field experiment 1968-69
Soil mechanical analysis, pH, and C.E.C.

Depth from surface cm	Percentage					pH	C.E.C. me/100g
	Clay	Silt	F.sand	C.sand	O.m.		
0-15	18·6	13·1	45·0	16·1	5·8	6·8	33·0
15-30	18·40	13·9	44·8	15·0	5·5	6·7	33·4
30-45	18·70	11·4	47·2	18·2	4·4	7·0	31·4
45-60	16·40	8·0	44·5	27·9	4·3	7·0	27·0

DESIGN OF EXPERIMENT:

Treatments.

Rates and times of fertilizer application.

The total amounts of nitrogen applied in the course of the experiment were none, 90, 120, and 150 kg. N/ha. These rates were applied in 2 dressings : the first was applied in the autumn (Dec. 2) and the other in the spring at tillering (May 22). The rates were in line with the recommendation regarding fertilizer application in South East Scotland (Anon, 1960; Holmes et al. 1959). The autumn and spring application were as follows:

1. A: autumn application; 2 rates A_1 30 kg. N/ha and A_2 60 kg. N/ha as $Ca(NO_3)_2.4H_2O$
2. S: spring application; 2 rates S_1 60 kg. N/ha and S_2 90 kg. N/ha using $NaNO_3$

The combinations of the overall applications were as follows:

1. A_1S_1 with an overall application of 90 kg. N/ha
2. A_1S_2 with an overall application of 120 kg. N/ha
3. A_2S_1 with an overall application of 120 kg. N/ha
4. A_2S_2 with an overall application of 150 kg. N/ha
5. No N with an overall application of 0 kg. N/ha

Each of these fertilizer combinations as well as the control (No N) was carried out under 2 systems:

1. Fallow; with no plants grown throughout the season. The soil was kept fallow by hand weeding and by chemical spraying.
2. With plants; the crop being winter wheat (var. Cappelle) drilled in rows 12 cm apart on Nov. 25, 1968.

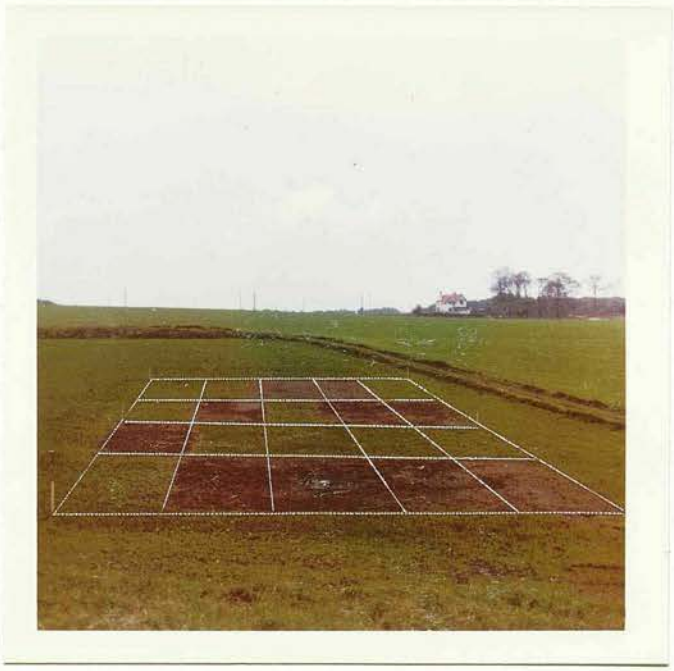
Therefore there were 5 treatments in each system (2 x 2) + 1:

(i) No N: A_1S_1; A_1S_2; A_2S_1; A_2S_2 for fallow

(ii) No N: A_1S_1; A_1S_2; A_2S_1; A_2S_2 for planted.

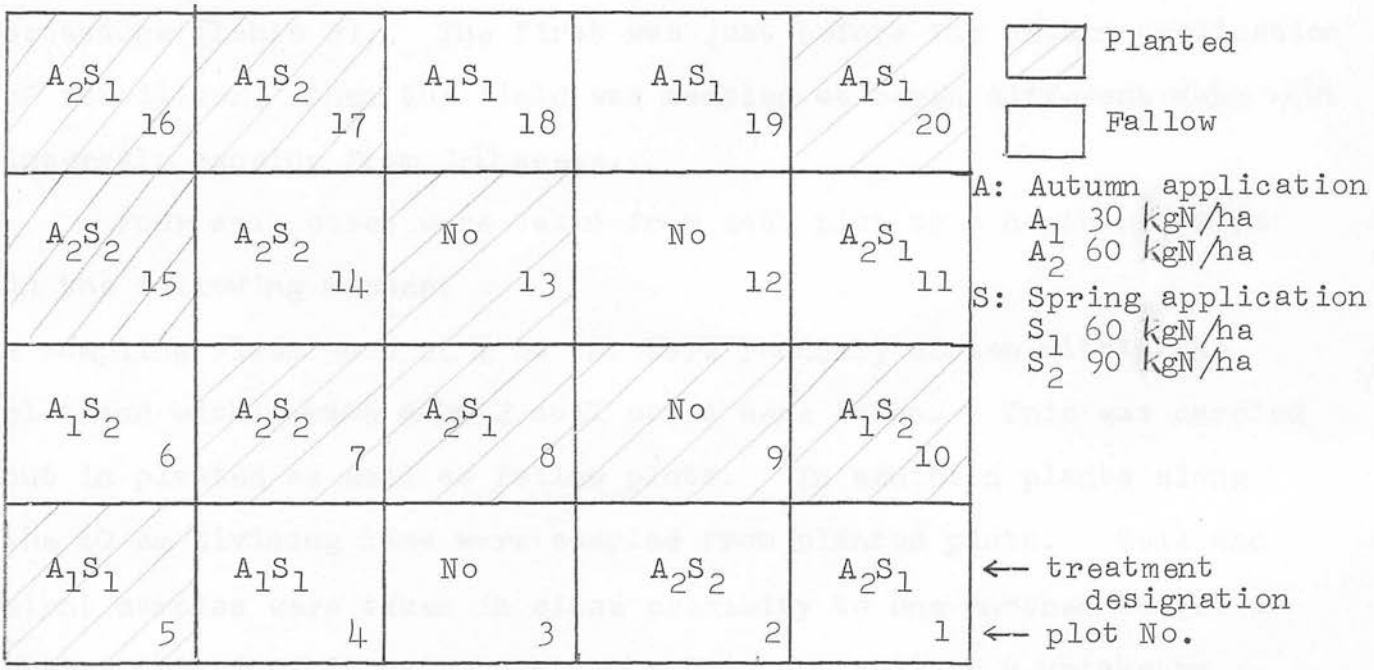
There were 2 replicates of each treatment; each replicate containing the 10 treatment combinations arranged in a random manner. Plate 2 and Fig. 1 show the experimental layout.

Plate 2: Field Experiment 1968-69.



A photograph of the site of experiment taken 6 weeks after the start of experiment.

Fig. 1. Field Experiment 1968-69.
Layout of the experiment.



Fertiliser materials and method of application:

Fertiliser materials used in the experiment were as follows:

(1) Autumn application: $Ca(NO_3)_2.4H_2O$ (11%N) technical grade. The material was ground to pass a 4 mm mesh sieve to ensure a uniform distribution of fertiliser

(2) Spring application: $NaNO_3$ (16%N). The material was extremely uniform in size (2 mm particles).

Sodium nitrate was used for spring application because of its uniformity of particle size as compared with calcium nitrate. Both fertiliser materials were mixed with coarse sand 1:1 (w:w) after weighing in order to facilitate handling. The fertiliser/sand mixture was broadcast by hand.

SOIL SAMPLING:

The soil was sampled to a depth of 60 cm. on 8 different occasions (Table 2). The first was just before the autumn application of fertiliser; then the field was sampled at seven different dates with intervals ranging from 3-11 weeks.

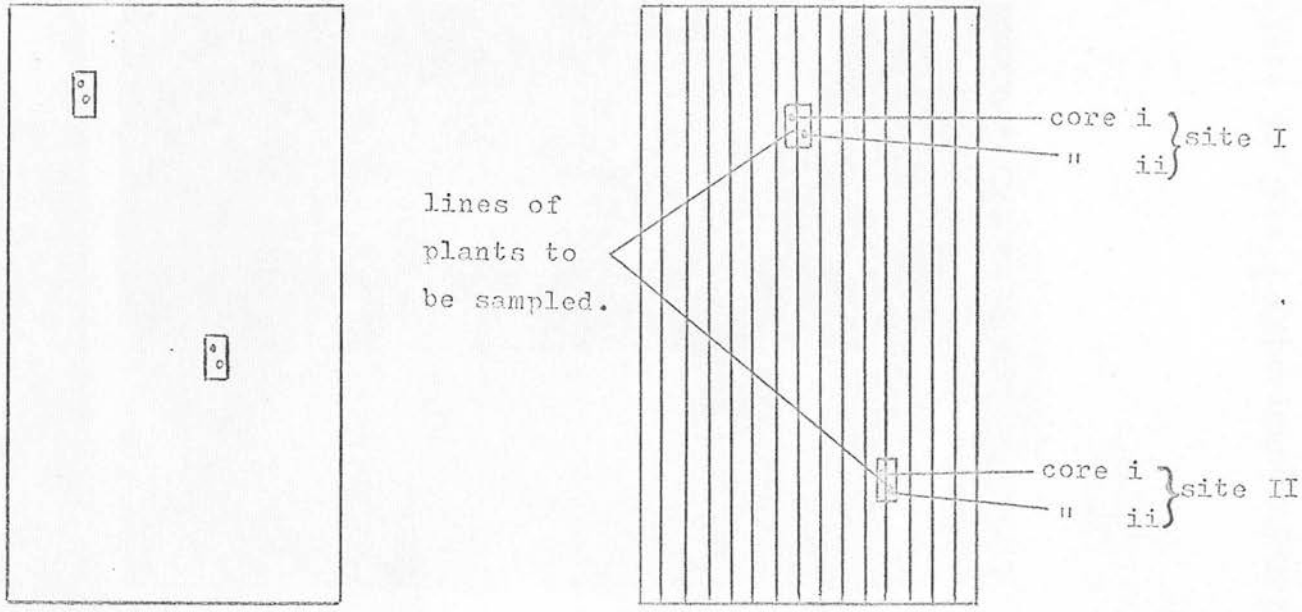
Four soil cores were taken from each plot to a depth of 60 cm in the following manner:
2 sampling sites each 24 x 60 cm. were randomly chosen within the plot and within each site 2 soil cores were taken. This was carried out in planted as well as fallow plots. In addition plants along the 60 cm dividing line were sampled from planted plots. Soil and plant samples were taken in close proximity to one another to get a better relationship between N content in the soil or N uptake by plant. Fig. 2 shows a diagram of the positions of sampling cores within a planted and unplanted plot.

Each core was cut into four equal sections of 15 cm each in the manner shown in Plate 3.

PLANT SAMPLING:

Except at the final sampling when plant samples were taken at harvest and the soil was sampled 6 days later, sampling of plants was done just prior to soil sampling (Table 2). The wheat plants in the middle of the sampling site (24 x 60 cm) were cut about 2 cm. above the soil surface using a 'Wilkinson' hand grass cutter. At the end of the season the planted plots were combine-harvested and the yields of grain and of straw were measured and recorded.

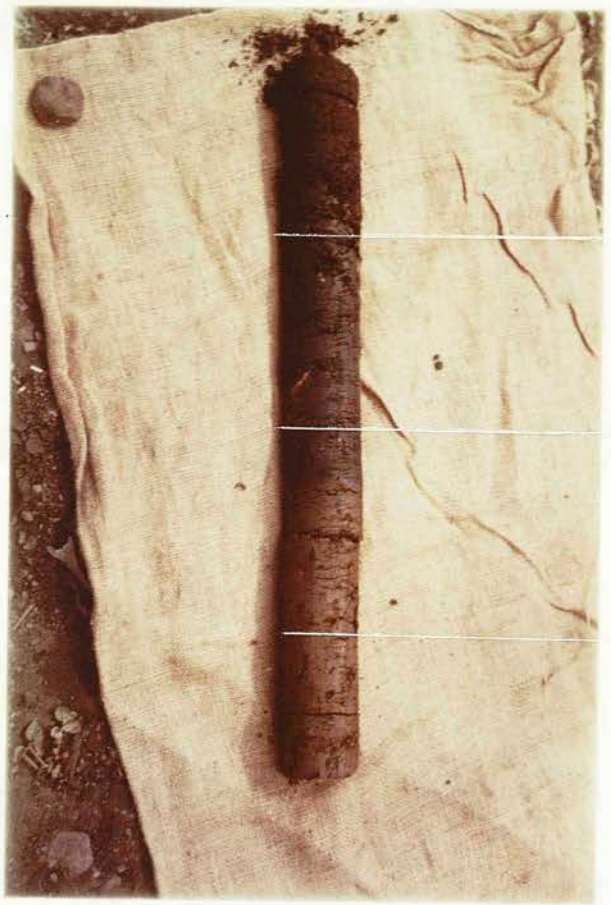
Fig. 2 . Field Experiment.
A diagram showing cores and sites
of soil samples within a plot.



FALLOW
PLOT

PLANTED
PLOT

Plate 3: Field Experiment 1968-69



Horizon 1 0 - 15 cm.

Horizon 2 15 - 30 cm.

Horizon 3 30 - 45 cm.

Horizon 4 45 - 60 cm.

Soil Core 60 cm. long.

Table 2: Field Experiment 1968-69.

Data and Intervals of soil and plant samplings

Month	Date	Weeks from start of experiment	Intervals between samplings (weeks)	Soil Sampling	Plant Sampling	N.B.
Dec.	2.12.68	0	0	Prelimi-nary		A
Dec.	23.12.68	3	3	1st	1st	*Incomplete sampling
Jan.	14.1.69	6	3	2nd	2nd	
Feb.	25.2.69	12	6	3rd	3rd	
May	12.5.69	23	11	4th	4th	
May	22.5.69					S
June	23.6.69	29	6	5th	5th	
July	23.7.69	34	5	6th	6th	
Sept.	16.9.69		7		7th	Harvest
Sept.	22.9.69	42	8	7th		

A: Date of autumn application

S: Date of spring application

* Samples were taken from one replicate only

Westher conditions made a complete sampling impossible on the first occasion. Heavy snow had fallen immediately after sampling the first block (i.e. plots 1 - 10; see Fig. 1) i.e. one replicate. The snow remained on the ground for 7 days making it impossible to obtain samples from the remaining block (i.e. plots 11 - 20) under similar conditions to Block I. The time required to sample the

whole experimental area at any one sampling varied from 3 to 4 days depending on the weather and soil conditions.

SOIL SAMPLING EQUIPMENT:

Description.

The soil cores were taken by means of the soil corer modified by Robertson (1968) and used by Lockhart (1968) in his research project. A steel cylinder is driven into the soil by a heavy weight. Equipment similar to the one used in this experiment is reported by Welbank and Williams (1968).

The sampling equipment (Plate 4) consists of a steel cylinder 7·5 cm. in diameter and 90 cm. long fitted with a sharp edge; this is driven into the soil by means of a heavy cast-iron 'dumper'. The 'dumper' is manipulated by hand and slides over a 96 cm. rod of steel which ends with a round thick steel disc which fits into the upper end of the steel cylinder.

Operation.

The steel cylinder is placed vertically with the cutting edge in the soil surface, the action with the steel rod and 'dumper' is then fitted into the upper end of the cylinder. By lifting up the dumper and allowing it to fall down the rod under gravity (Plate 5) the cylinder is driven down into the soil. When 60 - 63 cm. of cylinder is in the soil, the dumper and rod are removed and the cylinder is pulled out. This is done by means of an iron rod that slides horizontally through 2 holes facing each other near the upper part of the cylinder. The cylinder and contents are placed

Plate 4: Field Experiment 1968-69.

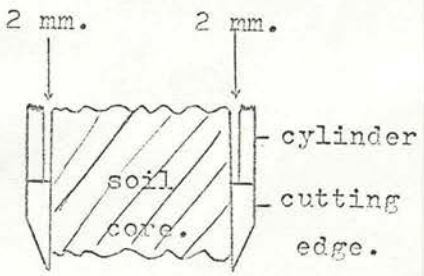
Soil Corer

horizontally over a clean sheet of material (textile, paper, or plastic). By using a wooden cylinder about 90 cm. long with one end which just fits into and moves through the steel cylinder, the soil core is pushed out of the cylinder of the blunt end of it. The push is exerted on the core through the lower sharp-edged end of the cylinder.

Plate 5: Field Experiment 1968-69.

Operation of Soil Corer

Fig. 3. Field Experiment. A diagram of the cutting edge and cylinder of the soil corer.



It is important to mention here that the compaction between the soil core and the internal surface of the cylinder while driving the cylinder into the soil was minimal. This is due to the bigger internal circumference of the cylinder as compared to that of the cutting edge which allowed for 2 mm gap between the soil core and the cylinder (Fig. 3).

COMMENTS ON THE SCHEDULE OF SAMPLING

Four factors governed the time intervals between samplings.

1. Seasonal variations in weather which affect the quantity of nitrogen in the soil:

   Because of the wetter conditions during autumn-winter in the South-east of Scotland, it was considered necessary to sample at short intervals in order to follow the movement of fertilizer nitrogen during that period.

2. Time-lapse after fertilizer application:

   The sampling intervals immediately after nitrogen application were short but they became progressively longer. It was considered more appropriate to have a short time-interval following fertilizer application when most of fertilizer nitrogen would be present within the profile (0 - 60 cm.). The intervals immediately after autumn application were as short as possible, i.e. 3 weeks; thereafter the intervals were lengthened to between 6 and 11 weeks. The same principle was applied to the samplings after the spring application when there was a 5 - 6 weeks interval immediately after application and another 8 weeks later.

3. Stage of plant growth:

   With no established plant cover to combat leaching of N (partly at least) intervals between sampling were kept as short as possible (autumn-winter period). With plant cover (in planted plots) intervals were not as short in order to allow for effective uptake of nitrogen.

4. Weather conditions affecting proposed time schedule:

In a number of cases, sampling had to be postponed because of unfavourable weather such as heavy rain or snow. This occurred in two occasions a) at the first sampling when half the experimental area was not sampled at the time, b) heavy rain occurred immediately after plant sampling/harvesting rendering it difficult to soil-sample. There was therefore a time-gap of one week between plant and soil sampling.

ASSESSMENT OF THE EXTENSION OF WHEAT ROOTS

This assessment was carried out after harvest in two plots; one which had received no fertilizer nitrogen and the other receiving 150 Kg N/ha. The purpose was to illustrate the root extension as a result of nitrogen application.

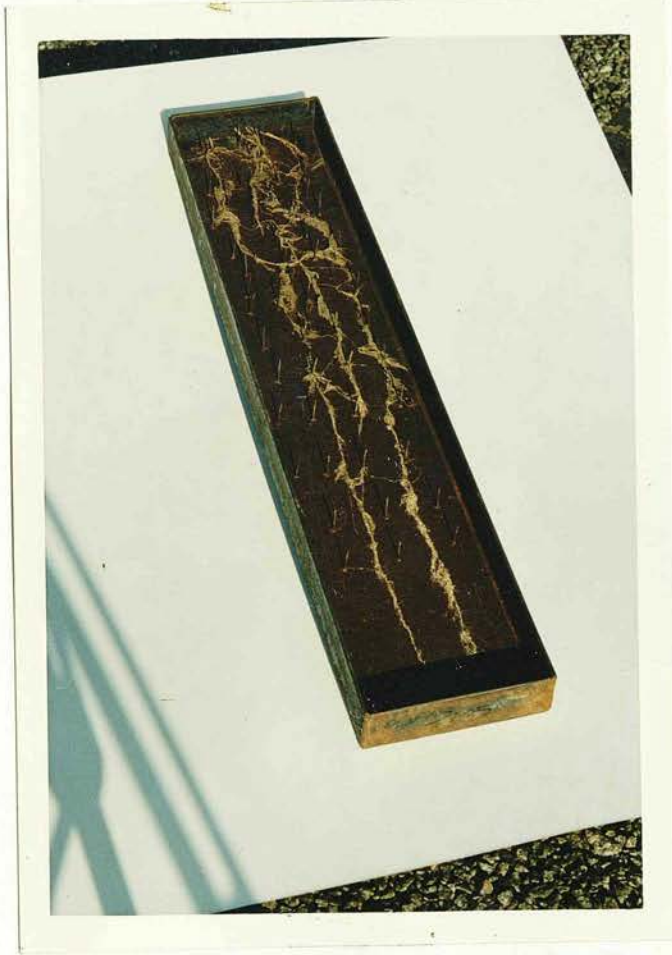
Procedure:

After harvest, two soil profiles were dug out to a depth of 75 cm. and removed on a steel frame. The frame supported a sheet of hard-board with nails pointing towards the soil profile. Plate 6 shows one of the monoliths taken from the site of the 1969 field experiment. Then, after repeated alternate freezing (for 24 hours) and thawing (for 24 hours), the soil was washed out leaving the roots. Plate 7 shows the roots in the steel frame after removal of the soil. The nails through the hardboard prevent the roots from being washed out with the soil. Alternate freezing and thawing was to facilitate the removal of soil particles without tearing the roots.

Plate 6: Field Experiment

Soil monolith

Plate 7: Field Experiment



Root extension

(B) GREENHOUSE EXPERIMENT I

LOSSES OF FERTILIZER NITROGEN FROM SOIL COLUMNS

OBJECTIVES:

This experiment was designed with the object of studying the movement of NO_3-N in a soil column. The results from the field experiment had suggested that a considerable movement of fertilizer nitrogen had taken place within the soil profile. A remarkable change in the content of soluble nitrogen had occurred with time in top soil compared with the subsoil. This experiment was designed in order to throw more light on the effect of some factors on the rate of NO_3-N movement in soil columns. Columns of top-soil and subsoil were put under 2 soil plant systems with and without applied NO_3-N and with 3 different watering régimes.

EXPERIMENTAL:

Treatments:

Soils: T top soil 0 - 30 cm
S sub soil 30 - 60 cm
The soils were air-dried, passed over a 6 mm. mesh riddle before mixing 1:1 (w:w) with coarse sand (average diameter 4 mm.)

Nitrogen rates: N_0, 0
N_1, equivalent to 60 Kg. N/ha as $Ca(NO_3)_2.4H_2O$ on the basis of surface area.

Soil: plant systems, F: fallow
C: sown (cropped) with rye grass

Watering régimes: R_1: 60% of water holding capacity
R_2: 90% of water holding capacity
R_3: 120% of water holding capacity

The W.H.C was determined after allowing excess water to drain from water-saturated columns

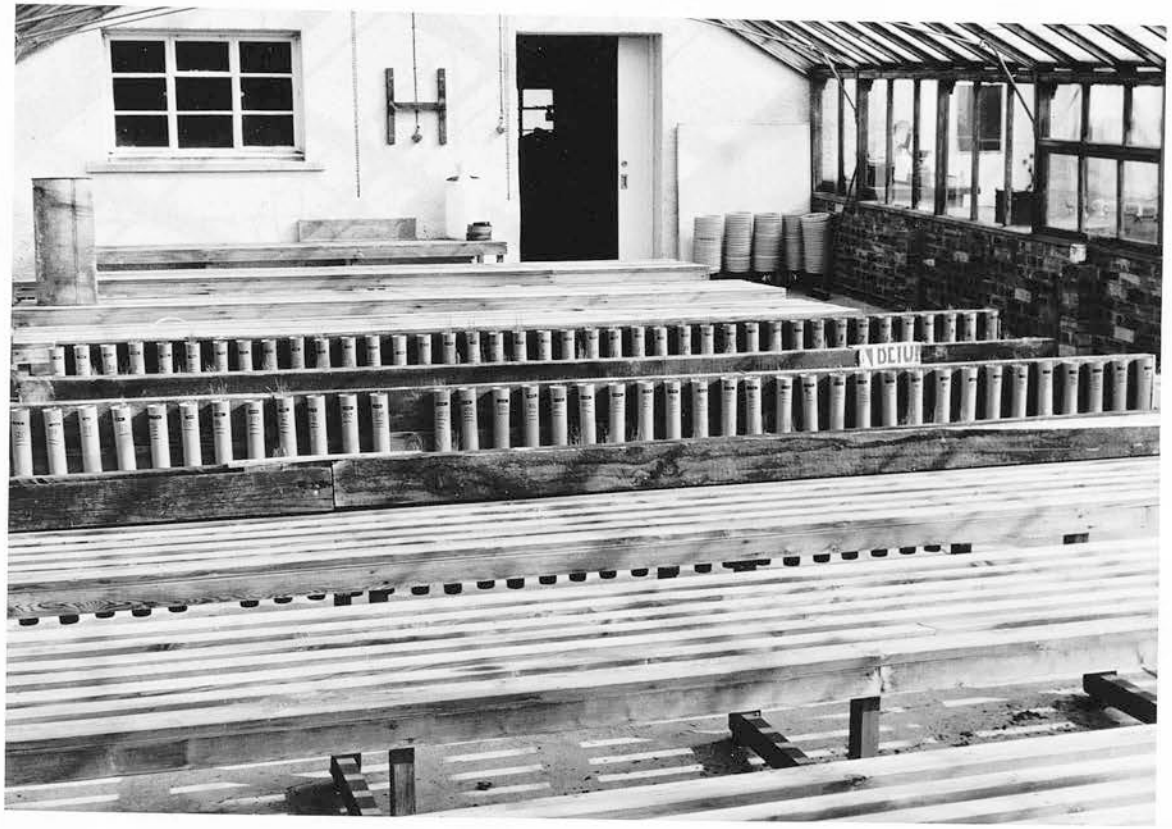
Samplings: Three samplings at 3 dates 3, 5, and 7 weeks following application of fertilizer. The sampling effect was contained in main plots, and the other treatments in sub plots. Sampling was carried out by taking whole tubes at each of the three dates.

Thus the design was: $(2 \times 2 \times 2 \times 3/3) \times 2$
S N C R samplings Replicates: factorial.

Procedure:

1·7 Kg of soil-sand mixture were weighed into a series of polythene tubes 5·9 cm. in diameter and 48 cm. long, closed at one end with a polythene beaker having small holes to allow drainage. The weight of soil-sand mixture was sufficient to form a soil-sand column 45 cm. long within the tube. The tubes were then suspended along the long sides of three benches in the greenhouse (Fig. 5; Plate 8). A polythene beaker was placed under each tube to collect the leachate. The soil in each tube was then brought to a moisture content of 60% of its water holding capacity. Then, in those columns where plants were to be grown, 20 seeds of ryegrass were sown and these were covered with 2 - 3 mm. of fine sand to keep the surface of the soil column moist and prevent 'capping' of soil when watering. 2 days following emergence, the plants were thinned out to 14 seedlings per tube. The plants were allowed to develop for 7 days

Plate 8: Greenhouse Experiment I.



Losses of fertilizer N from soil columns;
Layout of experiment.

following emergence before applying the nitrogen where appropriate in 10 ml solution per column. The moisture contents were then adjusted to the experimental values and watering was carried out every 24 - 48 hours to bring the columns to the required moisture content.

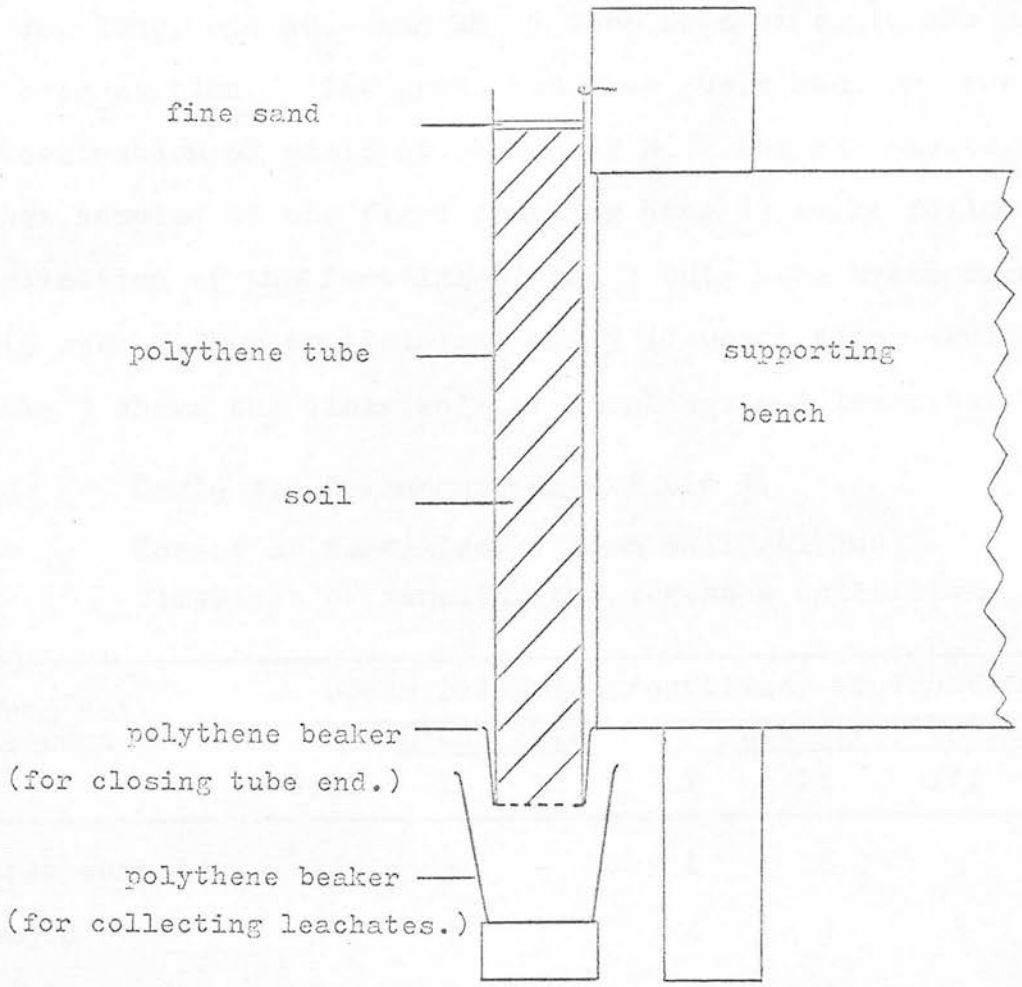


Fig. 5 . Greenhouse Experiment I; Losses of fertilizer nitrogen from soil columns. A diagram of a soil column unit.

Sampling:

At each sampling, the columns were cut into 3 sections, each 15 cm. long, and NO_3- and NH_4-N were determined in the moist soil in each section. The grass had previously been cut for the determination of yield of DM and of N. One cut was taken from those tubes sampled at the first sampling date (3 weeks following application of the fertilizer) and 2 cuts were taken from samplings 2 (5 weeks after application) and 3 (7 weeks after application). Table 3 shows the time-table of samplings and leachates collection.

Table 3: Greenhouse Experiment I.
Losses of fertilizer N from soil columns;
Timetable of sampling and leachate collection.

From soil columns of	Weeks following fertilizer application							
		Grass cuts		Leachates Collections				
	Soil	I	II	I	II	III	IV	V
First sampling	3	3	-	1	2	3	-	-
Second "	5	3	5	1	2	3	5	-
Third "	7	3	7	1	2	3	5	7

(C) GREENHOUSE EXPERIMENT II

EFFECT OF IGNITING SOIL ORGANIC MATTER ON THE AVAILABILITY OF FERTILIZER NITROGEN

OBJECTIVES:

The top soil (0 - 30 cm.) at the site of the field experiment in 1969 (Niddry Mains Farm, Winchburgh) had a higher content of NH_4+NO_3 nitrogen than the subsoil (30 - 60 cm.) and this was thought to be due to the higher organic matter content of the surface soil (5.7%). An experiment was designed to investigate the effect of organic matter on the behaviour of fertilizer nitrogen. Sufficient soil for the experiment was dug from the top 30 cm. and after air drying and sieving, about half the soil was ignited at 350°C for 24 hours to destroy the organic matter. Coarse sand was mixed with both ignited and unignited soils in the ratio 2:1 (w:w) to improve aeration.

EXPERIMENTAL:

195 g aliquots of the soil:sand mixture were placed in polythene pots (with holes in the bottom), 7 cm. deep and with upper and lower diameter of 6 and 5 cm. respectively.

Treatments:

Soils: S_1 Ignited soil

S_2 The same soil without pretreatment

Nitrogen rates: N_0, 0

N_1, 25 ppm N applied as $Ca(NO_3)_2$

N_2, 50 ppm N applied as $Ca(NO_3)_2$

Soil-plant systems: F, fallow

C, sown (cropped) with rye grass.

Replicates: Four replicates of the factorial combination of soils, nitrogen rates and systems.

The design was therefore (3 x 2 x 2)x 4 factorial. Fig. 5 and Plate 9 show the layout of the experiment.

15 seeds were sown in each pot; 7 days later plants emerged, and 2 days after emergence each pot was thinned to 10 plants. Fertilizer was applied 10 days following emergence. Water was added to the soil daily maintaining the moisture content at 60% of the water holding capacity.

Sampling:

After 40 days of growth (i.e. 30 days after application of N) each pot was emptied of its contents and in the planted pots the soil was separated from roots by shaking gently allowing the roots to be harvested along with plant tops. After roots had been washed with water to get rid of soil particles, plants were dried at 110°C for 24 hours and roots separated from tops before weighing. Nitrogen was determined in both components. NO_3^- and NH_4^+ N were determined in a representative soil sample taken from each pot.

Fig. 5. Greenhouse Experiment II.
Effect of soil organic matter on fertilizer nitrogen.

LAYOUT

REPLICATE

	1	2	3	4	5	6		25	26	27	28	29	30
I	S_1N_1F	S_2N_1C	S_1N_1C	S_1N_2F	S_1N_0C	S_1N_0F	III	S_2N_2F	S_2N_1F	S_1N_1F	S_1N_2C	S_2N_0F	S_2N_2F
	7	8	9	10	11	12		31	32	33	34	35	36
	S_2N_0F	S_2N_2F	S_2N_2C	S_1N_2C	S_2N_1F	S_2N_0C		S_1N_0F	S_1N_0C	S_2N_0C	S_2N_1C	S_1N_2F	S_1N_1C
	13	14	15	16	17	18		37	38	39	40	41	42
	S_2N_0F	S_1N_2F	S_1N_2C	S_1N_0F	S_1N_2C	S_2N_1F		S_1N_1F	S_1N_2F	S_1N_2C	S_2N_1F	S_2N_1C	S_2N_0F
II							IV						
	19	20	21	22	23	24		43	44	45	46	47	48
	S_1N_1C	S_2N_0F	S_1N_1F	S_2N_0C	S_1N_0C	S_2N_1C		S_1N_1C	S_2N_2F	S_2N_2C	S_1N_0C	S_1N_0F	S_2N_0C

Designations:

Soils: S_1: Ignited soil; S_2: Unignited soil

N treatments: N_o: no nitrogen; N_1: 25 ppm N; N_2: 50 ppm N

System: F: fallow; C: cropped.

Plate 9. Greenhouse Experiment II.

Effect of soil organic matter on fertilizer nitrogen

LAYOUT

(D) LABORATORY EXPERIMENT

EFFECT OF AGGREGATE SIZE ON LEACHING LOSS OF NO_3-N

OBJECTIVES:

The purpose of this experiment was to investigate the effect of aggregate size on the rate of leaching of NO_3-N. Two ranges of aggregate size were chosen, 1 mm.- 3 mm. and 3 mm.- 6 mm. in diameter, from Longrig field on one of the Edinburgh School of Agriculture farms, which had been under barley for the previous 4 years; its known history is as follows:-

Year:	1956-57	1958	1959-60	1961-63	1964	1965-68
Crop:	grass	cereals	grass	cereals	grass	cereals

The soil for this experiment was removed from the 0 - 22·5 cm. surface by spade.

PREPARATION OF SOIL;LAY-OUT OF EXPERIMENT:

After air-drying, the soil was sieved to obtain the 2 aggregate-size categories. Leaching tubes, 2·5 cm. in diameter and 14 cm. long, were filled with air-dry aggregates to a depth of 10 cm. by weighing 36·5 g into each tube and adjusting to 10 cm. depth by tapping. This ensured a similar total volume for both small and large aggregates. A 2 mm. layer of glass wool was placed at the bottom end of each column to prevent particles from falling through the leaching tube and at the top to protect aggregates from direct impact of added water. Four tubes were filled with each aggregate size and 29·2 mg. N as KNO_3 were added to two of each four (equivalent to 800 ppm N in air-dry soil). To simulate field

practice the KNO_3 was spread as uniformly as possible on the glass wool cover and 5 ml. distilled water was added very slowly by pipette to dissolve the KNO_3 and allow the air-dry aggregates to absorb the solution. A 100 ml. beaker was placed under each tube to collect the leachate. Watering and collection of leachates were carried out over 24 days in the manner presented in Table 4. Two size grades of gravel (1 - 3 and 3 - 6 mm. in diameter) also in 10 cm. columns received the same N treatments as soil aggregates.

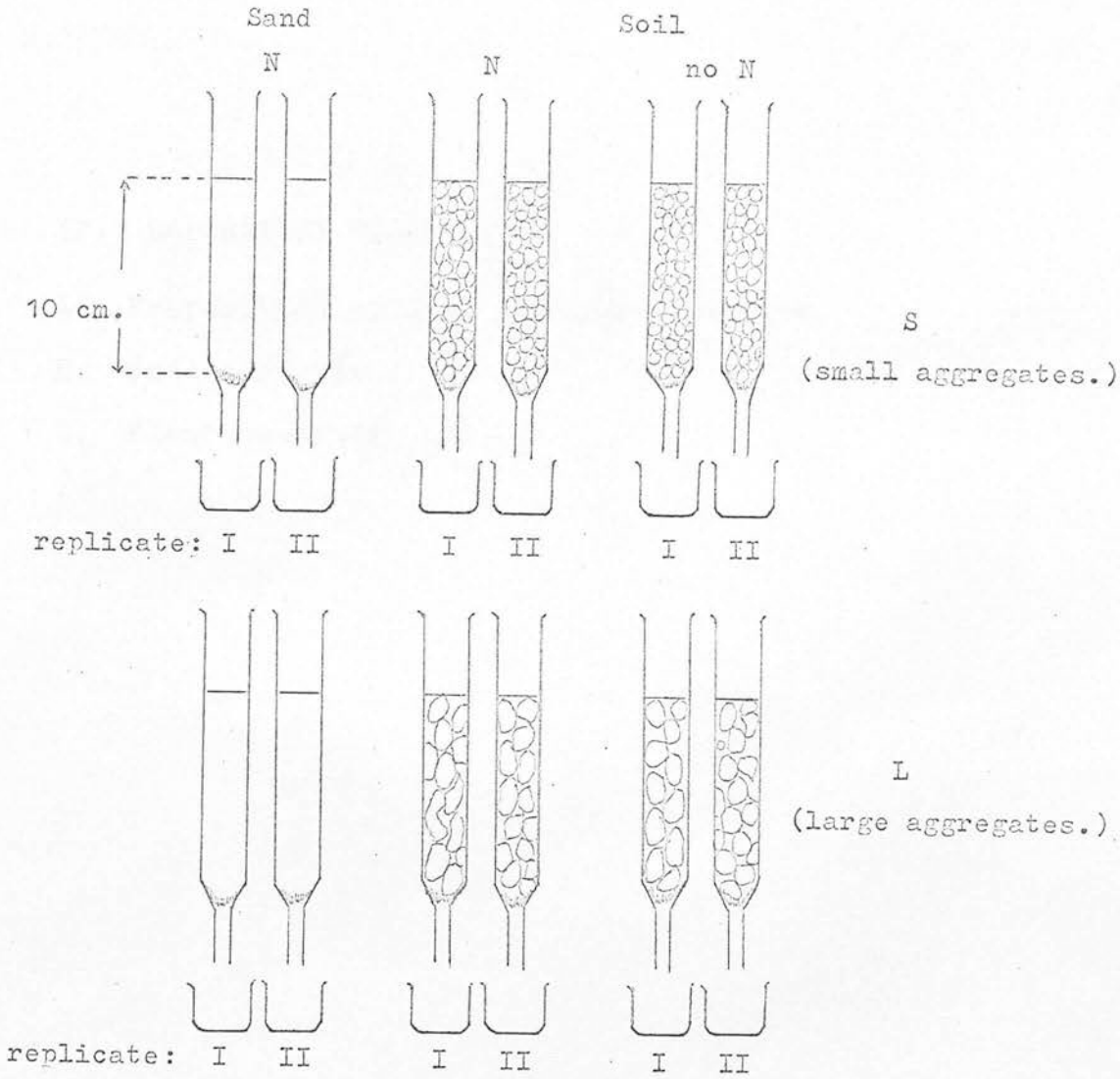
Table 4. Laboratory Experiment.
Time schedule of watering and collection of leachates

Time days	Water added ml	Leachate ml. * S	L		Time days	Water added ml	Leachate ml. * S	L		Time days	Water added ml	Leachate ml. * S	L		Time days	Water added ml	Leachate ml. * S	L	
Start	5				8	5				20	10				22	10		
1	5				"	10				"	10				""		37·0	38·1 IX
"	5				9	10				"				VII	23	10		
		1·1	3·1 I				20·4	20·6 IV		21	10				"	10		
3	5				10	20				"	10				"	10		
"	5						19·8	19·3 V		"	10				"	10		
6	5				10	10						23·7	27·9 VIII		"		31·8	32·6 X
"		3·7	4·6 II		13	10				22	10							
7	5				"	5				"	10							
"		4·2	3·9 III		"		5·6	7·8 VI		"	10							

*S: small aggregates
L: large aggregates

Fig. 6 .Laboratory Experiment .

Lay-out of experiment.



(2) LABORATORY WORK

A. Preparation of soil and plant samples

B. Soil analysis

C. Plant analysis

LABORATORY WORK

(A) PREPARATION OF SOIL AND PLANT SAMPLES

The following preparations were carried out on samples from field experiment.

Soil:

The moist soil samples were stored until required for analysis at 2°C to keep activity of microorganisms at a minimum. Immediately before analysis, the moist samples were sieved and NO_3- and NH_4-N were determined on the fraction of moist soil passing the 2 mm. sieve. Samples were taken at the same time for moisture determination.

Plant:

Plant samples were dried overnight in the electric oven at 100°C, milled in a 'Christy and Norris' Laboratory mill and stored in plastic containers until required for analysis. Separate samples of grain and straw were taken at harvest and treated the same way.

(B) SOIL ANALYSIS

(1) Mechanical Analysis

The method used for mechanical analysis was adapted from Piper (1942) using the International scale which is presented in the following table.

Fraction	Diameter
Coarse Sand	2·0 - 0·2
Fine Sane	0·2 - 0·02
Silt	0·02 - 0·002
Clay	< 0·002

Reagents:

6% hydrogen peroxide

Conc. HCl

10% NH_4OH solution

Procedure

20 g air-dry soil were weighed into 600 ml. beaker to which 60 ml. of 6% hydrogen peroxide were added and the contents were heated gently with stirring to prevent vigorous frothing. The soil suspension was allowed to cool, it was then diluted to 150 ml. with distilled water and sufficient conc. HCl to make the solution about $\frac{N}{5}$ acid. After standing for one hour, the suspension was filtered through an 18 cm. Whatman No. 3 filter paper and washed with up to 500 ml. distilled water.

The filter paper was then spread out on a large clock-glass and the adhering soil particles transferred by a jet of hot distilled

water to a 0·2 mm. sieve held over a 600 ml. beaker until the soil had been washed out, then the filter paper was rolled into a loose ball and squeezed until no further liquid was obtained. The soil on the sieve was rubbed gently with a rubber bung and washed with a jet of hot distilled water until no further particles of soil could be removed. Then the soil was transferred to a weighed crucible; dried at 105°C and reweighed to give percentage coarse sand.

The soil suspension left in the 600 ml. beaker was transferred to a one-litre shaking bottle; diluted to about 800 ml. with distilled water containing 50 ml. 10% NH_4OH solution and then shaken in an 'end-over-end' shaker at 30 - 40 rev./min. until the sample was thoroughly dispersed (about 24 hours). After shaking, the suspension was transferred to a one-litre measuring cylinder; the volume was made to 1 litre and mixed by rapid inversion for about one minute. After allowing to settle for 4 minutes 48 sec. (at 20°C), a 20 ml. aliquot of suspension was taken at a depth of 10 cm. with a pipette; this aliquot was transferred to a weighed silica basin, dried at 105°C and reweighed to give percentage silt + clay.

The contents of the cylinder were thoroughly mixed by inversion and left to stand for 8 hours (at 20°C) when another 20 ml. aliquot was taken, by pipette, at a depth of 10 cm., dried and weighed to give percentage clay.

After the supernatant liquid had been poured off, the residue was washed into 600 ml. beaker and filled with water to a depth of 10 cm. The suspension was stirred up and allowed to settle for 4 minutes 48 sec. (at 20°C) before decanting the supernatant liquid.

This was repeated till the supernatant liquid was clear, indicating that all the silt and clay had been removed. The residue was dried in the beaker at 105°C and weighed to give the fine sand.

(2) Determination of Soil Reaction (pH)

Soil pH was measured in a 1:2 w/v suspension of air-dried soil and water, using PYE pH meter with a glass electrode.

(3) Determination of NO_3- and NH_4-N

The soil available NO_3-N and NH_4-N were extracted with sodium acetate-acetic acid (Morgan 1941).

a) Extraction:

(i) Reagent

Extracting solution: sodium acetate-acetic acid extracting solution (pH 4·8) was prepared by dissolving 200 g sodium acetate ($CH_3COONa3H_2O$) in about 1 l. of distilled water containing 60 ml. glacial acetic acid. The final volume was made up to 2 l. when cool.

(ii) Procedure

Fresh moist soil equivalent to ~25 g air-dry soil were weighed into a 100 ml. shaking bottle and 50 ml. extracting solution were added. 0·4 g. activated carbon (B.D.H.) were added to decolorise the extract. After shaking for 30 min., the extract was filtered through a Whatman No. 3 filter paper into a 100 ml. conical flask.

b) Determination of NO_3-N:

The soil NO_3-N extracted by the sodium acetate-acetic acid solution was determined using the brucine method of Robinson et al. (1959).

(i) Reagents:

Range of standard solutions containing 0 - 100 ppm. N as KNO_3 in distilled water.

5% w/v brucine in glacial acetic acid.

Conc. H_2SO_4 (sp. gr. 1·84)

(ii) Procedure

A 2 ml aliquot of leachate was pipetted into a 50 ml. pyrex test tube and the following reagents added, mixing thoroughly after the addition of each reagent: 0·5 ml brucine; 5 ml conc. H_2SO_4. After 15 min, the yellow colour developed was measured in an E.E.L. Absorptiometer with filter No. 601 (425 mμ) using cells with an optical length of 5 mm. The instrument was set to zero with a solution of potassium chromate of sufficient concentration to bring the reading of the blank to just above zero. When a 2 ml aliquot of soil extract gave a reading above the maximum standard, a smaller aliquot was taken and diluted to 2 ml with extracting solution.

c) Determination of NH_4-N

Exchangeable NH_4-N was determined in the sodium acetate acetic acid extract using Nessler's reagent (Peech and English, 1944).

(i) Reagents

Range of standard solutions containing 0 - 10 ppm N as $(NH_4)SO_4$ in distilled water.

Nessler's reagent: Analar Nessler's reagent.

NaOH-tartrate solution: 40 g sodium tartrate were dissolved in about 300 ml distilled water, 13 g sodium hydroxide were added, and the solution diluted to 1·5 l. 5 per cent gum acacia reagent: 10 g powdered tum acacia were dissolved in 195 ml. distilled water and 5 ml Nessler's reagent were added. It was left for a few days to allow any precipitate to settle out. The solution was prepared as required.

(ii) Procedure

A 2 ml aliquot of soil extract was pipetted into a 50 ml pyrex test tube and the following reagents were added in quick succession.

5 ml NaOH- tartrate; 8 drops gum acacia; 4 drops Nessler's reagent, mixing well after the addition of the last reagent. The yellow colour developed was measured after 15 minutes in an E.E.L. Absorptiometer using filter No. 601 (425 mμ) and cells with an optical length of 5 mm. The instrument was set to zero with distilled water. A series of standard and a calibration curve was drawn. When a 2 ml aliquot of soil extract gave a reading above the maximum standard, a smaller aliquot was taken and diluted to 2 ml with extracting solution.

(C) PLANT ANALYSIS

DETERMINATION OF TOTAL N IN PLANT SAMPLES

Nitrogen was determined by the Kjeldahl method; using 50 ml Kjeldahl flasks. The organic matter was oxidised by sulphuric acid in the presence of K_2SO_4 and $CuSO_4$ converting the complex nitrogenous compounds into the ammonium form which was distilled over and collected in boric acid and determined by titration with diluted sulphuric acid (Markley and Hann, 1925).

Reagents

conc. H_2SO_4 (sp.gr. 1·84)

$K_2SO_4.CuSO_4$ tablets containing about 1·9 g K_2SO_4 and 0·6 g $CuSO_4$ per tablet.

60% w/v NaOH (tech.) in water.

4% Boric acid in distilled water.

0·05 N H_2SO_4

H_2O_2 (100 vol.)

Mixed indicator: by dissolving 5 g bromocresol green and 0·1 g methyl red in 100 ml. of 95% ethanol. The solution was adjusted to its blueish purple mid-colour at pH 4·5 with either dilute NaOH or HCl.

Procedure

A sample (0·5 g) of dried plant material was weighed into a 50 ml. Kjeldahl flask, then 0·5 ml. water, a glass bead and 10 ml. conc. H_2SO_4 were added. After allowing to cool, 4 ml. H_2O_2 were added very carefully followed by 1 tablet of catalyst after the initial vigorous reaction had subsided. The contents were heated

gently until the organic matter had decomposed and the solution was clear and then heated for another 1 - 1½ hours. The contents of the flask were allowed to cool and transferred to a 500 ml. Kjeldahl flask and diluted with about 200 ml. distilled water, 30 ml. 60% N.OH solution were added gently to form a separate layer at the bottom of the flask followed by small pieces of granulated zinc. Before clamping the flask in position on the distillation apparatus, the contents were mixed. The ammonia evolved on heating was collected in boric acid solution (25 ml. 4% boric acid + 25 ml. distilled water) in a 500 ml. conical flask and heating was continued for 30 minutes. The ammonia then titrated against 0·05 N H_2SO_4 using the mixed indicator.

IV : RESULTS

FIRST:

FIELD EXPERIMENT 1969

"Effect of fertilizer N on fallow and planted systems".

Contents:

A. Some aspects of the statistical analysis

B. Some aspects of the presentation of results

C. Presentation of results

A: SOME ASPECTS OF THE STATISTICAL ANALYSIS

The two objectives of this experiment were:

1. To assess the errors associated with the method of soil sampling employed.
2. To study the transformation and movement of mineral N in the soil.

[1] Assessment of errors involved in soil sampling.

In studies on changes occurring to mineral N in soil, various techniques have been used by various workers. There was no limit to the number of cores which should be taken per hectare to give a reliable representation of the status of the nutrient in the soil. However, Kolenbrander (1968) stated that the minimum limit was 30 - 40 core/ha.

The following number of cores given per plot and per hectare have been used by various workers.

Reference	Area of plot m^2	No. of cores per plot	No. of cores per ha
Gasser (1962)	18 to 90	2 to 3	111 - 333
Nommik (1966)	45 to 50	6	1200 - 1333
Kolenbrander (1968)	5	10	20000
Current field expt.	33	4	1212

Although Kolenbrander's work (Kolenbrander, 1968) concerned an assessment of soil heterogeneity studying values obtained from soil

cores, he did not make any recommendation regarding the optimum number of cores taken to give an accurate representation of the soil.

In these experiments, mentioned above, there was no attempt made to take into consideration the effect of the location of plant rows in relation to the location of the soil-core sample.

The two aspects of a) the optimum number of cores per plot and b) the technique of soil sampling constituted an important part of this current investigation.

a) The number of soil cores per plot:

The work of Gasser (1962) in Britain suggested that four cores per plot would be within the practical and economic possibilities of soil sampling in this type of experiment.

b) Core-sampling technique:

It was thought that a core taken in between plant rows would give relatively higher values of mineral N than one taken closer or inside plant rows (due to effect of plant roots). Therefore, to give equal chance for cores taken in between plant rows to those taken in the plant row, 2 areas of 30 cm. across plant rows and 60 cm. along them were chosen at random in each plot. Two soil cores were taken at random within each area.

[2] Investigation of the changes of mineral N

Without dispensing with the value of the statistical results regarding the reliability of the design and sampling technique, the change of mineral N with depth and time was studied as revealed by results obtained from the experiment. Data obtained were processed

and statistically analysed for this purpose.

The following statistical analyses were carried out on data obtained:-

i. Estimation of errors associated with the experiment:-

In order to test the errors associated with the technique of sampling (see page 32) a preliminary statistical analysis (analysis of variance) was performed on NO_3-N results of the January sampling regarding H_1.

The analysis of variance table was as follows:

Source of variation	d.f.	M.S.	Notes
Blocks	1		2 Blocks: i.e. replicates
Treatments	5		6 treatments: 2 systems x 3 rates of N 0 and 2 autumn treatments
Plots Residual [Error]	13	M.S. (1)	
Total	19		20 plots of experiment
"within plots"			
Area I vs. Area II	20	M.S. (2)	) Hierarchical analysis
Within area			)
Core i vs. core ii	40	M.S. (3)	)
TOTAL	79		

The following are the most important sources of variation with which associated errors are calculated.

1. Plot residual: associated error i.e. $\sqrt{M.S._{(1)}}$ = 13·82

2. Within plots (area I vs. area II) $\sqrt{M.S._{(2)}}$ = 7·80

3. Within area (core i vs. core ii) $\sqrt{M.S._{(3)}}$ = 7·95

These results suggest that there was a large component of variation associated with plots, a smaller component of variation was associated with areas or cores. Therefore increasing the number of cores and/or areas per plot would reduce the error associated with plots only slightly.

An increase in the number of plots, rather than the number of cores per plot, is the best way to reduce the effects of soil heterogeneity and decrease the errors associated with sampling.

ii. Statistic analysis of experiment:-

Statistical analysis was performed as follows:-

Values of variates:

1. As far as any specific horizon (H_x) is concerned, at any specific sampling date, there were four values (for any of NO_3-N; NH_4-N; or (NO_3 + NH_4)N), derived from the chemical analysis of each of the four soil cores taken per plot (see page 32). Those values correspond to the 4 soil columns taken per plot (see page 32) at any sampling time.

2. The mean of those 4 values (regarding H_x and sampling month x) in each plot was derived to represent that plot (treatment replicate) upon which analysis of variance technique was performed. This was done separately on 2 bases:

a) each horizon at each sampling date

b) the sum of the 4 horizons (profile) at each sampling date.

3. The analysis of variance table was as follows:

Source of variation		d.f.
Block	B	1
System (planted vs. fallow)	C	1
Autumn application (A_1 vs. A_2)	A	1
Spring application (S_1 vs. S_2)	S	1
Overall application (A_1S_1; A_1S_2; A_2S_1; A_2S_2)	A.S.	1
Effect of fertilizer N (no N vs. N)	N	1
	C.A.	1
	C.S.	1
	C.A.S.	1
	C.N.	1
ERROR		9
Total		19

A two-way table of fallow vs. planted against the different nitrogen treatments (no N, A_1S_1, A_1S_2, A_2S_1, A_2S_2) was obtained.

No statistically significant results were obtained during the first 4 samplings; some statistically significant ones were obtained in the late 3 samplings (June, July, and Sept.). However, in presenting results and discussion, as much emphasis has been given to the general trend of pattern as to the statistically significant

effects. This offers a more constructive representation and coherent understanding of the results.

A list of statistically significant effects

a: Soils

Sampling	NO_3 A	NO_3 S	NO_3 N	NO_3 C	NH_4 A	NH_4 S	NH_4 N	NH_4 C	$NO_3 + NH_4$ A	$NO_3 + NH_4$ S	$NO_3 + NH_4$ N	$NO_3 + NH_4$ C
H_1 June	**		**	***	*							***
July		**	**	***						**	*	***
Sept.				***								*
H_2 June	**			***					*			
July				***				*				***
Sept.			*	***								
H_3 June				***								
July				***							*	*
Sept.			*	***								
H_4 June				***								
July	*			***								
Sept.				**								
$H_1 + H_2 + H_3 + H_4$ (i.e. profile)												
June	*		*	***								
July		*	**	***								
Sept.			*	***								

b: Plants

June				*
July	*			***
Sept.				***

Note:

*, **, and *** denote ·05, ·01, and ·001 levels of probability.

A, S, N and C are treatment effects (see p. 70)

B: SOME ASPECTS OF THE PRESENTATION OF RESULTS

1. In presenting the results, the following abbreviations are used:

   (i) for rates and times of application of N:

   A_1: 30 Kg. N/ha applied in autumn.

   A_2: 60 Kg. N/ha applied in autumn.

   S_1: 60 Kg. N/ha applied in spring.

   S_2: 90 Kg. N/ha applied in spring.

   (ii) for soil horizons:

   H_1: horizon 1 (0 - 15 cm.)

   H_2: horizon 2 (15 - 30 cm.)

   H_3: horizon 3 (30 - 45 cm.)

   H_4: horizon 4 (45 - 60 cm.)

2. An attempt has been made to assess the effect of time on the pattern of movement of nitrogen from the soil surface down to the subsoil in both fertilized and unfertilized soils; the results are presented as histograms.

3. For convenience, the investigation has been divided into two periods, a: immediately following the autumn application of N during which period there are two rates of N viz. A_1 and A_2 and one control, and b: following the spring application where the treatments are control and four rates of N resulting from the factorial combination of rates and times of application of N.

4. The samplings are identified by date rather than by the number of weeks after commencement of the experiment, since it is easier

To appreciate possible seasonal effects using the former method. Initially, the fallow treatments are separate from the cropped and the nitrate nitrogen from the ammonium.

Calculation of data:

The concentration of NO_3- and NH_4-N in soil was recorded in ppm air-dry and particles < 2 mm. in diameter; since particles of > 2 mm. contained negligible quantities of N. In order to relate N recovered with that applied, these results were converted into Kg./ha.

The quantity of air-dry soil particles (< 2 mm.) in each horizon was assessed from 10 cores (each 60 cm. long), taken at random at the commencement of the experiment. (The quantity of < 2 mm. particles decreased with increase in depth). Having the concentration of N in soil particles and the quantity of soil present in each horizon, it was possible to calculate the quantity in Kg./ha using factors calculated in the following way:

a: The weight of < 2 mm. soil particles (mean of 10 sample cores) is

H_1 = ·545 Kg.

H_2 = ·538 Kg.

H_3 = ·446 Kg.

H_4 = ·403 Kg.

b: To obtain the weight of soil particles per hectare-horizon it is necessary to multiply by:

$$\left(\frac{\text{Area of ha.}}{\text{Area of soil column surface}} \right) = \frac{\text{Area of ha.}}{\text{Area x } r^2 \text{ of column's surface cm}^2}$$

$$= \frac{10^8}{3{\cdot}14 \times 14{\cdot}52}$$

$$= 2{\cdot}191 \times 10^6$$

Thus the weight of soil particles in one hectare-horizon is:

H_1 = 1194 t

H_2 = 1179 t

H_3 = 976 t

H_4 = 883 t

c: ∴. The following factors allow ppm to be converted to Kg./ha.

H_1 ppm x 1·194

H_2 ppm x 1·179

H_3 ppm x 0·976

H_4 ppm x 0·883.

Because of the large standard errors associated with the results from the field experiment, few differences were statistically significant (the main source of variation is discussed on pp 68-69). Therefore in the Results and Discussion Sections (Chapters IV and V) mean main effects only are considered. The tables of results (in the Appendix) and Figures, however, present the results from each treatment combination.

Using the main effects of each treatment, it was possible to obtain a clearer understanding of the results, in the absence of statistical significance.

C: PRESENTATION OF RESULTS

[1] CONTENTS OF NO_3-N& NH_4-N IN SOIL HORIZONS

a: Fallow Soil

NO_3-N: (Fig. 7)

In those plots which did not receive fertilizer nitrogen, nitrate N underwent a similar pattern of change throughout the season in each of the 4 horizons. However there was a different pattern for the surface horizons compared with those in the subsoil where fertilizer nitrogen was applied. In each of the 4 horizons of the unfertilized soil the nitrate N content progressively increased from Dec. to Feb. then declined in May, June and July and increased again in Sept. In the fertilized plots, the NO_3-N in H_1 decreased slightly from Dec. to May but increased in June, following the spring application of fertilizer. This was followed by a decrease in July and Sept. In H_2, H_3 and H_4 the pattern was similar to the corresponding horizons in the control, where the contents in each of those 3 horizons increased in Jan. and Feb. than decreased in May and in June there was little change followed by a decrease in July and an increase in Sept.

In general, each horizon in the fertilized plots contained more NO_3-N at each sampling date than its counterpart in the unfertilized plots. This was most pronounced in Dec., following the autumn application, and in June and July following the spring application. The biggest difference in the NO_3-N content of H_1 between the fertilized and the unfertilized plots occurred in Dec. and June,

i.e. about 4 weeks after application of fertilizer N. The longer the interval between application of fertilizer and sampling, the smaller the difference became.

In Jan. and Feb., H_1 and H_2 of the A_2 plots contained more NO_3-N than those horizons in the A_1 plots. In May, this difference was also shown by H_3 and H_4. Following the spring application, the NO_3-N content of fertilized soil was greater than that of the unfertilized soil. This occurred consistently in all horizons during June to Sept. The deeper the horizon the smaller its content of NO_3-N; this occurred in the unfertilized soil at all times during the season. On the other hand H_2 of the fertilized soil contained more NO_3-N than H_1 in Jan. (6 weeks following N application) and Feb. (12 weeks following N application). Apart from those 2 cases, this treatment followed the pattern of the unfertilized plots, i.e. $H_1 > H_2 > H_3 > H_4$.

A greater change in the NO_3-N content occurred in H_1 and H_2 than in H_3 and H_4 over the period immediately following fertilizer application. This was more pronounced after the autumn application viz. between Dec. and Jan. where the NO_3-N content of H_1 and H_2 increased by 10 and 27 Kg. N/ha respectively; increases between a fraction of a Kg. and 2 Kg./ha took place in H_3 and H_4. Unfertilized plots showed an increase in all horizons through the same period but the increments were smaller and decreased with depth. During the period following the spring application the changes in H_1 and H_2 with time were greater than those in H_3 and H_4.

NH_4-N (Fig. 8)

Except for a decrease in Feb., a progressive increase in NH_4-N occurred between Dec. and May in both H_1 and H_2 in fertilized and unfertilized plots; and also in H_3 and H_4 between Dec. and Feb. A decrease occurred between the end of the above intervals and the July sampling followed by an increase in Sept.

In Dec. the horizons of the fertilized plots contained more NH_4-N on average than the unfertilized and this difference continued throughout the winter and early spring (i.e. Dec. - May) but was not as pronounced in the later months as in Dec. In June and also to a lesser extent in July, following the spring application of fertilizer, H_1 of fertilized plots contained more NH_4-N than unfertilized. The contents in H_2, H_3, and H_4, on the other hand, were less in fertilized than unfertilized during the same period. In Sept., only the A_2 plots contained more NH_4-N than the control in each of the 4 horizons.

The autumn application of fertilizer had a more pronounced effect on NH_4-N content of the soil than that applied in the spring. This effect was most marked shortly after fertilizer application (in Dec.) and also in Sept. Plots receiving A_2 contained more NH_4-N than those with A_1 in each of the 4 horizons in both Dec. and Sept. The reverse occurred in Feb., May, June and July, i.e. less NH_4-N in A_2 plots than in A_1. In June, following the spring application the higher the combined autumn and spring applications the lower the NH_4-N content in the horizons.

During Dec. - Jan., the NH_4-N content of each horizon in a profile was, in general, similar, but in Feb., the NH_4-N content

increased with the depth and $H_1 < H_2 < H_3 < H_4$. However in June - Sept., the contents decreased with the increase in depth.

$(NO_3 + NH_4)N$ (Fig. 9)

The contents of $(NO_3 + NH_4)N$ in the unfertilized H_1 and H_2 increased between Dec. and Jan. as a result of the increase in both NH_4- and NO_3-N fractions during that period. Thereafter a decrease took place in Feb. mainly due to the decrease in NH_4-N. This decrease continued throughout the succeeding period till May during which time the contents of total $(NO_3 + NH_4)$ decreased due to a decrease in both NO_3 and NH_4. The contents of both H_3 and H_4 on the other hand increased progressively for a longer space of time (Dec. - Feb.). It was not until May that a decrease occurred in H_3 and H_4 and continued until July followed by an increase in Sept. In the fertilized plots there was a little change in H_1 and H_2 between Dec. and Jan. despite a slight increase in NO_3-N in H_2 during the same period. In Feb., mainly because of the large decrease in NH_4-N, there was a decrease in $(NO_3 + NH_4)N$, and in May an increase occurred, again due to NH_4. Little change occurred to H_1 in June compared with May despite a decrease in NH_4-N during the same period; this was due to the increase in NO_3-N following the application of fertilizer. The contents in H_2 on the other hand decreased in June. Later on in July both H_1 and H_2 decreased in their contents, followed by an increase in Sept. A pattern resembling that of the unfertilized plots occurred in H_3 and H_4 of fertilized

plots i.e. an increase took place during Dec. - Feb. followed by a decrease till July after which another increase took place in September.

In Dec. and June, following autumn and spring application respectively, there was a greater (NO_3 + NH_4)N in each of the 4 horizons (except in H_3 in June) of fertilized plots compared with the unfertilized. With the lapse of time following the fertilizer application, the difference favouring fertilized plots decreased in H_1 and H_2, but was unchanged in H_3 and H_4. In May there was a pronounced difference between fertilized plots and control.

Due to the increase in NH_4-N contents in A_2 compared with A_1 in Dec. and Sept., and to the decrease also in NH_4-N which took place in May - June, the A_2 plots contained slightly more (NO_3 + NH_4)N than the A_1 in Dec. and Sept. and less in May and June.

In general, the deeper the horizon the smaller its contents of (NO_3 + NH_4)N. This occurred throughout the season particularly at the beginning (Dec.) and end (Sept.); the big decline in NH_4-N in H_1 and H_2 in Feb. was counterbalanced by a pronounced increase in NO_3-N during the same time thus restoring this pattern of a decrease in mineral N with increase in depth.

The difference between upper and lower horizons decreased with time during Dec. - Feb.; while the difference between H_1 and H_4 ranged from 24 - 50 Kg. (NO_3 + NH_4)N/ha in Dec., it was only 2 - 18 in Feb. The increase which took place in H_3 and H_4 between Jan. and Feb. on one hand and the decrease which occurred in H_1 and H_2 during the same period on the other resulted in a very slight difference between horizons in Feb. During Feb. - Sept. the differences between horizons increased with time.

b: Planted Soil

NO_3-N (Fig. 10)

The pattern of change in NO_3-N throughout the season was different in fertilized plots from those of the control, but this difference was confined to H_1, since H_2, H_3 and H_4 of both treatments behaved in a similar way. In all horizons of the unfertilized soil and in H_2, H_3 and H_4 of the fertilized soil, there was a progressive increase in NO_3-N from December up to February but a decrease followed in May which continued till July when the content reached a minimum. There was an increase in September.

Between December and January, i.e. following the autumn application of fertilizer there was a decrease in the NO_3-N content of H_1. On the other hand, there was an enrichment in H_2 - though not as obvious in A_1 as in A_2 plots - during December to February. Between February and July, the NO_3-N content of H_1 and H_2 decreased progressively followed by an increase in September.

Fertilized horizons contained more NO_3 than unfertilized and this was most marked in H_1 and H_2 shortly after the autumn application. Those 2 horizons maintained a greater content of NO_3-N over their counterparts in the unfertilized plots for 2 months (December and January) but the difference disappeared in February and reappeared in May. A smaller difference occurred from June to September. Fertilized H_3 and H_4 on the other hand maintained a higher NO_3-N content over their unfertilized counterparts during the January to May period; but little difference was shown during June to September.

The greater NO_3-N content of those plots receiving the higher rates of N compared with the lower, was displayed mainly in H_1 and H_2 particularly following the autumn application rather than the spring. While H_1 displayed this effect immediately after application, H_2 showed it slightly later. However, with time, this difference decreased. For example, H_1 of the A_2 plots generally contained more NO_3 than that of A_1 in December, but in February the underlying H_2 showed this effect. From June to July, the contents in all fertilized treatments were similar. In September, plots receiving S_2 contained more than those of S_1.

In general, the surface horizons contained more NO_3 than the deeper ones, and the order was in this sequence: $H_1 > H_2 > H_3 > H_4$; and the difference was greatest at the beginning of the season.

The gap between upper (H_1 and H_2) and lower (H_3 and H_4) horizons of fertilized plots underwent a decrease as the lapse of time following fertilizer application increased. This was due to the decrease in upper horizons which was accompanied by an increase in lower horizons.

NH_4-N (Fig. 11)

The pattern of change in NH_4-N in the planted plots with depth and with time was similar to that in the fallow, although the contents in the planted plots were generally less for any one horizon at any one time.

There was less NH_4-N in fertilized horizons than unfertilized during the December to February period. In May, however, the fertilized horizons, especially H_3 and H_4, contained more NH_4-N but

in June and July, after the spring application, there was, again, less NH_4-N in the fertilized horizons. In September, the fertilized H_1 contained less than the unfertilized but the situation was reversed in H_2 and contents in fertilized and unfertilized H_3 and H_4 were similar.

A_1 plots contained slightly more NH_4-N than A_2 in December, and less in January and February, but in May there was little difference. In June following the spring application, each of the 4 horizons of A_2 plots again had a greater NH_4-N content than the A_1 plots.

During December to January, the NH_4-N contents of the horizons of each treatment were, in general, similar; but in February there was a progressive increase in content with depth so that the order was $H_1 < H_2 < H_3 < H_4$. In May, the contents decreased with increase in depth and this pattern continued until the end of the season (September) in the unfertilized plots and July in the fertilized ones. In September, H_1 of the fertilized plots contained less than the underlying H_2, but the order between H_2, H_3 and H_4 was $H_2 > H_3 > H_4$.

The difference between the upper and lower horizons increased with time after the autumn application: in December the differences were small but in February H_1 and H_2 contained much less NH_4-N than in December while H_3 and H_4 contained far more, bringing the difference to its highest level. There was also a great difference between upper and lower horizons with time following spring application (June - September).

$(NO_3 + NH_4)N$ (Fig. 12)

In all treatments, the $(NO_3 + NH_4)N$ in H_1 and H_2 increased between December and January followed by a progressive decrease until July and an increase in September. The contents of H_3 and H_4, on the other hand increased between December and February after which a progressive decrease, continuing till July, started to take place.

In December the fertilized plots contained more $(NO_3 + NH_4)N$ than the unfertilized in each of the 4 horizons; this was due to the greater NO_3-N content in fertilized plots. In June, because of the smaller content of NH_4-N, the fertilized plots contained less $(NO_3 + NH_4)N$ in each horizon compared with the unfertilized.

In general, the A_2 treatments contained more than the A_1 plots during the December to January period; but there was an increase in June in each of the 4 horizons which was inversely related to the overall rate of fertilizer application; thus the order was $A_1S_1 > A_1S_2 = A_2S_1 > A_2S_2$. This effect was mainly due to the increase in NH_4-N. In July and September there was little difference between fertilized and unfertilized treatments.

Except in February when the $(NO_3 + NH_4)N$ contents of each of the 4 horizons were similar, the deeper the horizon the smaller its content.

As with fallow plots, the difference between the upper and lower horizons decreased with time during December till February and in February there was little difference between the four horizons in their contents of $(NO_3 + NH_4)N$. Thereafter (from February to September) the difference between horizons increased with time.

[2] CONTENTS OF NO_3- AND NH_4-N IN SOIL PROFILE

a: Fallow Soil (Fig. 13a)

NO_3-N

The NO_3-N contents of fertilized and unfertilized profiles increased during the winter (December to February) and decreased during the spring (February to May). In June, there was a slight increase in fertilized plots but the unfertilized ones continued to decrease. In July, the NO_3-N contents in the profiles of all treatments decreased and an increase followed in September.

More NO_3-N was present in fertilized profiles than in unfertilized following the autumn and spring applications. The NO_3-N content of the fertilized soil decreased with time and 2 - 4 months after application there was little difference between the treatments; at this stage some fertilized plots even contained less NO_3-N than the unfertilized.

In January and February, the A_2 treatments had a greater amount of NO_3 than those receiving A_1 and throughout the post-spring period (June - September) there was more NO_3 in the S_2 plots than the S_1.

NH_4-N

There was also an increase in NH_4-N in all treatments during December to January, but a decrease followed in February. In May an increase occurred followed by a decrease in July with an increase occurring in September.

Throughout the winter and spring (December - May) there was more NH_4 in fertilized than unfertilized, the reverse occurred during May - September and fertilized soils contained less NH_4-N.

The A_2 soils contained a greater amount of NH_4-N than the A_1 during the winter but there was no difference in the spring (May). In June, and after spring application, the higher the overall rate of fertilizer N application, the lower the content in soil profile; i.e. $A_2S_2 < A_1S_2 = A_2S_1 < A_1S_1$.

$(NO_3 + NH_4)N$

The slight decline in NH_4-N content in February caused the increase in $(NO_3 + NH_4)N$ which had taken place during the winter to last only until January with little change in February. The decrease in NO_3-N which took place between February and May was greater than the increase which occurred in NH_4-N during the same period thus rendering a decrease in $(NO_3 + NH_4)N$. During May to July, despite the spring application of fertilizer NO_3 which was reflected in an increase in NO_3-N in June, the continued pronounced decrease in NH_4-N caused a progressive decrease in $(NO_3 + NH_4)N$.

The nitrate fraction of the fertilized plots caused the contents of $(NO_3 + NH_4)N$ to surpass those of the unfertilized during the beginning of winter (December and January; 2 months following autumn application) and throughout the summer (June and July; about 3 months following spring application). In September A_2 contained more than A_1 or the unfertilized plots.

A greater $(NO_3 + NH_4)N$ content was shown in the A_2 plots compared with A_1 during the winter months (December to February). At the beginning of summer (June) the A_1 plots contained more $(NO_3 + NH_4)N$; this was due to the increase in the ammonium fraction of N. In July, plots receiving S_2 contained more than the S_1.

b: Planted Soil (Fig. 13b)

NO_3-N

The NO_3-N content of the soil profile increased throughout the winter (December to February) then decreased during the spring and summer (May - July) followed by an increase in September. In December, January and May the fertilized plots contained more NO_3-N than the unfertilized but during the summer, the fertilized contained less NO_3-N and in September there was very little between treatments.

There was very little difference between the A_2 plots and the A_1 during the winter (December - February) but in May there was less NO_3 in the A_2 plots. During the summer and beginning of autumn (June - September) however, the NO_3-N contents of the soil profile decreased with the increase in the overall rate of application i.e. $A_1S_1 > A_1S_2 = A_2S_1 > A_2S_2$.

NH_4-N

Between December and January, in all treatments there was an increase in NH_4-N content followed by a decrease in February. In May, however, while the unfertilized plots continued their decrease, though very slightly, the fertilized treatments increased, reaching nearly the same level as in January. Between May and July there was a progressive decrease in all treatments; thereafter, in September, an increase occurred. Fertilized plots contained less NH_4-N than unfertilized throughout the winter (December to February) and also in June and September. In May (6 months after autumn application) and July (2 months following spring application)

the reverse occurred and more NH_4-N was present in fertilized soil profiles.

In general A_1 plots had slightly more NH_4-N than A_2 in December - June and later on in September. In June, the higher the overall rate of application, the lower the content of NH_4-N.

$(NO_3 + NH_4)N$

As with NO_3-N, $(NO_3 + NH_4)N$ increased between December and February after which month a decrease occurred and continued until July; in September there was an increase. Only in December and May did the fertilized plots contain more $(NO_3 + NH_4)N$ than the unfertilized.

Generally throughout the season (December - September) there was a decrease in $(NO_3 + NH_4)N$ content with the increase in the rate of fertilizer application.

[3] THE MINERAL N CONTENT OF FALLOW SOIL IN RELATION TO THE PLANTED

a: In Soil Horizons

NO_3-N (Fig. 14)

While the contents of NO_3-N in H_1 and H_2 were greater in December in the planted plots than in the fallow, the fallow H_3 and H_4 surpassed their planted counterparts. In January, only H_1 of the planted maintained a superiority over the fallow; other horizons (H_2, H_3 and H_4) of the planted treatments contained, on average, similar amounts to their fallow counterparts. In February, planted H_1 and H_2 lost their superiority over the fallow and the fallow H_1 and H_2 now contained higher amounts of NO_3-N than those in the planted horizons. From May until the end of the experiment each of the planted horizons contained less than their counterparts. This difference increased with time; it was smallest in May and at a maximum in June and July, particularly regarding H_1 and H_2.

NH_4-N (Fig. 15)

During December - February, the planted treatments contained less NH_4-N in each of the four horizons compared with those in the fallow. In May, however, the planted H_1 and H_2 contained less NH_4-N than those in their fallow counterparts, but there was little difference between fallow and planted in H_3 and H_4. In June each of the 4 horizons in planted plots, again, contained less NH_4-N than those in the fallow. In July, the reverse occurred and the

planted soils contained more NH_4-N in each of their four horizons. In September, planted plots, receiving no N and A_1 contained slightly more NH_4-N in H_1 than the corresponding fallow plots, but the A_2 contained less when planted than when fallow. H_2, H_3 and H_4 contained more when planted than when fallow.

$(NO_3 + NH_4)N$ (Fig. 16)

In December, the planted plots contained less $(NO_3 + NH_4)N$ in each horizon than the fallow. In January, there was little difference but in February and May fallow horizons generally contained slightly more $(NO_3 + NH_4)N$ than planted. During the period from June - September, there was far more $(NO_3 + NH_4)N$ in each of the fallow horizons - particularly H_1 and H_2 - than in the planted.

b: In Soil Profile (Figs. 17 & 18)

NO_3-N

In all treatments, an increase occurred between December and February followed by a decrease in May. In June, control plots (both fallow and planted) and fertilized planted plots continued their decrease; fertilized fallow showed no change in S_1 plots and an increase ranging from 10 - 35 Kg. N/ha in S_2 plots. All treatments underwent a decrease in July and an increase in September.

The highest amount of NO_3-N in the soil profile occurred in February. During December to February there was a much greater increase (80 - 100 Kg. N/ha) in the unfertilized soil than in the fertilized (25 - 75 Kg. N/ha).

In December there was more NO_3-N in planted than in fallow soils. At each sampling date from January - May, planted and fallow profiles contained similar amounts of NO_3-N; between June and September less NO_3-N was shown in planted than in fallow profiles.

Particularly during June to September the higher the rate of application of N the greater the difference in NO_3-N contents between fallow and planted consistently favouring the fallow.

NH_4-N

Throughout December - September the pattern of change with time was similar in both systems; an increase in January followed by a decrease in February, then another increase in May followed by a decrease in June and July and finally a third increase in September. The highest NH_4-N content occurred in January. During December - May there was less NH_4-N in planted than in fallow and the reverse occurred in June to September.

$(NO_3 + NH_4)N$

An increase took place during December - January (in some cases till February) and a decrease between May and July followed by an increase in September. During December to February the unfertilized plots had slightly more $(NO_3 + NH_4)N$ in their fallow than in their planted profiles. On the other hand, in the fertilized plots there was more $(NO_3 + NH_4)N$ in the fallow than in the planted profiles. During May to September $(NH_4 + NO_3)N$ contents of the planted profiles were less than those in the fallow, but the difference was very small in the unfertilized profiles; the higher the rate of

application of fertilizer the bigger the difference.

The patterns of (NO_3 + NH_4)N in the two systems were mainly due to the NO_3-N fraction.

[4] UPTAKE OF N BY PLANT

(Table 6 and Fig. 19)

Table 6. Field Experiment 1969
N uptake by wheat (above ground parts only)

Sampling Date	Jan.	Feb.	May	June	July	Sept.	% recovery of fertilizer N in Sept.
N treatment			Kg./ha				
0	1·3	2·2	9·8	25·9	32·7	37·0	
A_1S_1	2·3	2·4	9·9	69·4	72·7	97·9	67
A_1S_2	2·1	2·1	10·4	71·5	109·1	117·1	67
A_2S_1	1·9	2·0	13·6	90·6	119·4	120·1	70
A_2S_2	1·8	2·1	12·2	98·5	109·0	152·3	77

During January and February the uptake of N by plants was independent of fertilizer treatment (Table 6; Fig. 19). From May onwards there was a greater uptake from the fertilized than from the unfertilized soils although this difference was much smaller in May than in the period June - September. In May, while uptake from the unfertilized plots was 9·8 Kg./ha, the fertilized plots had uptakes ranging from 9·9 to 13·6 Kg./ha. In June, the increase in N uptake was far greater in fertilized than in

unfertilized plots; uptake in the control plots was 25·9 while uptakes in fertilized ranged from 69·4 to 98·5 Kg. N/ha.

The higher the fertilizer rate, (combined autumn + spring application) the greater the uptake of nitrogen; the smallest uptake from the fertilized treatments was from A_1S_1 (90 Kg. N/ha rate of application).

The greatest N uptake was from those plots which received the higher autumn rate (A_2). Although A_1S_1 and A_2S_1 provided the same (120 Kg. N/ha) overall (autumn + spring) rate of application, the higher autumn rate (A_2) produced the higher uptake, and this was consistent throughout the period from June, following spring application, till harvest in September.

Summarizing the results of N uptake: the order was $A_2S_2 > A_2S_1 > A_1S_2 > A_1S_1$.

[5] CONTENTS OF MINERAL (NO_3 + NH_4)N IN SOIL PROFILE AND N UPTAKE

(Fig. 20)

The effect of plant cover on the loss of mineral N was much more pronounced during May - September than during January - February. The smaller (NO_3 + NH_4)N content in the soil profiles of planted plots compared with fallow ones (Fig. 18) was more than compensated by the amount of N taken up by the plants during May - September (Fig. 19) and therefore the N uptake + profile content of (NO_3 + NH_4)N in planted soils was much higher than the profile content of

(NO_3 + NH_4)N in fallow soil during this period (Fig. 20). During January - February, on the other hand N uptake was too small (2 Kg. N/ha) to have much effect.

It was in the fertilized treatments rather than the unfertilized that the soil (NO_3 + NH_4)N + N uptake by plants in planted soils exceeded soil (NO_3 + NH_4)N of the fallow soils due to the pronounced N uptake by plant particularly in the N treated plots. The greater the N rate of application the bigger this difference favouring planted treatments became.

[6] METEOROLOGICAL MEASUREMENTS (Figs. 21 & 22)

a: Rainfall (Fig. 21a & b)

The weekly rainfall during the post-autumn application period was on average far higher than during the post-spring period. The amounts of precipitation precipitated during the week immediately prior to each sampling were 27, 32, 23, 40, 19, 18 and 8 mm. for December, January, February, May, June, July and September sampling respectively (Fig. 21a). Taking into consideration the total amount of precipitation during intervals between any two successive samplings (Fig. 21b) the biggest was between February and May samplings.

b: Precipitation-transpiration (Fig. 21c)

There was a moisture surplus during the winter but a deficit during the summer.

c: Soil Temperature (Fig. 22)

Soil temperature (10 cm. deep) fluctuated above and below zero for a brief period in February.

Fig. 7. Field Experiment: contents of NO_3-N in soil horizons.

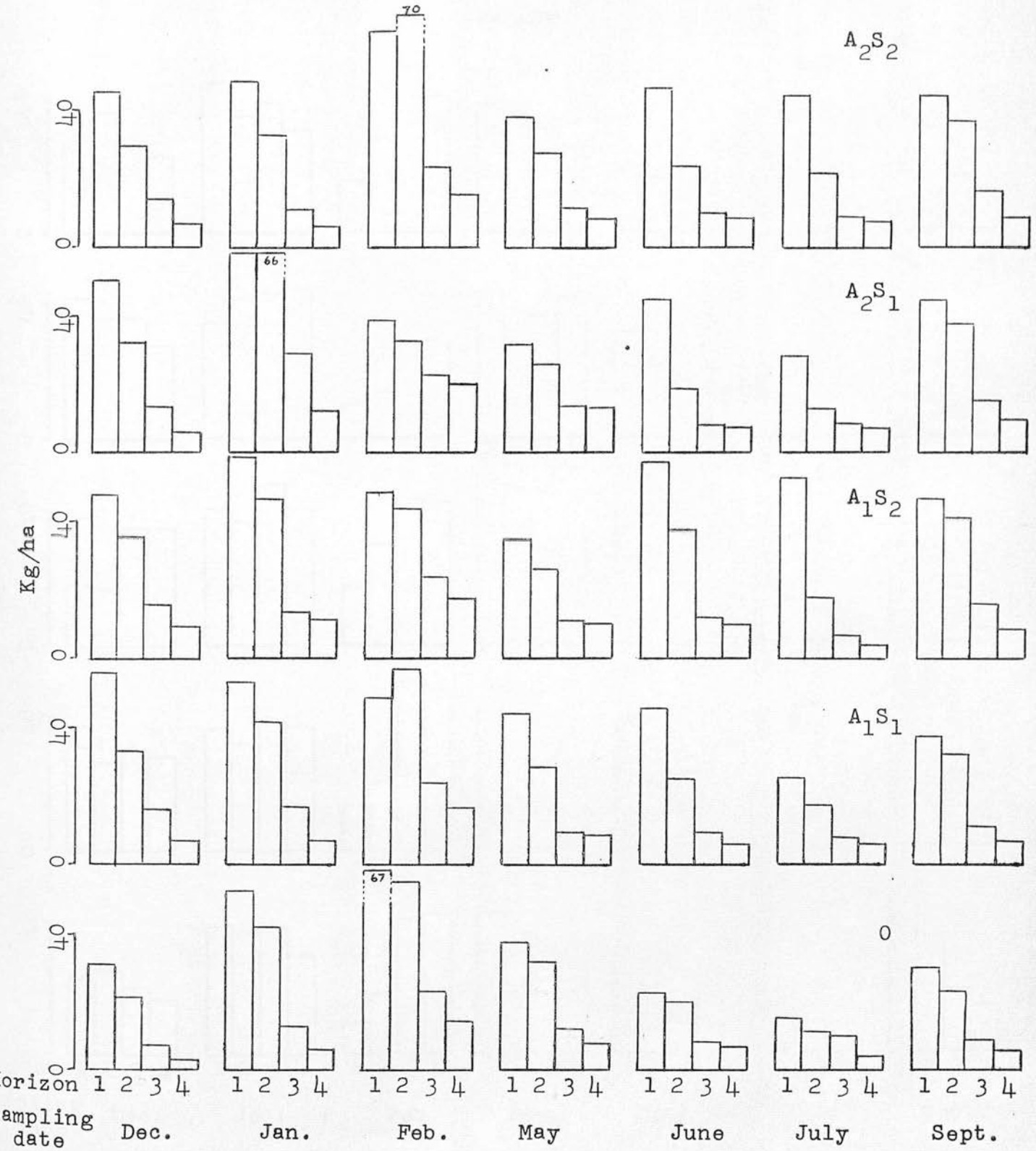


Fig. 8. Field Experiment: Contents of NH_4-N in soil horizons.

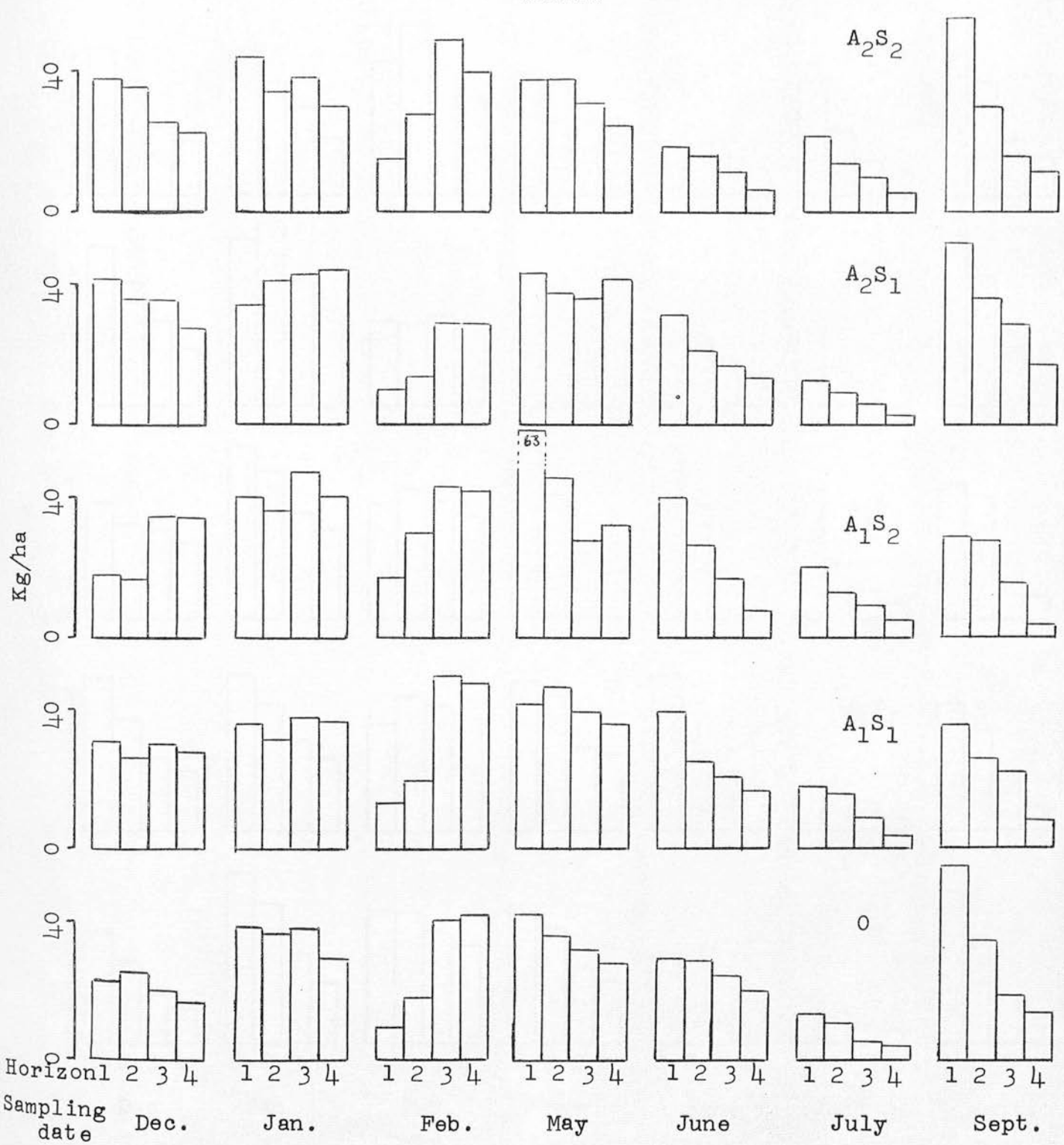


Fig. 9. Field Experiment: Contents of $(NO_3 + NH_4)N$ in soil horizons.

FALLOW

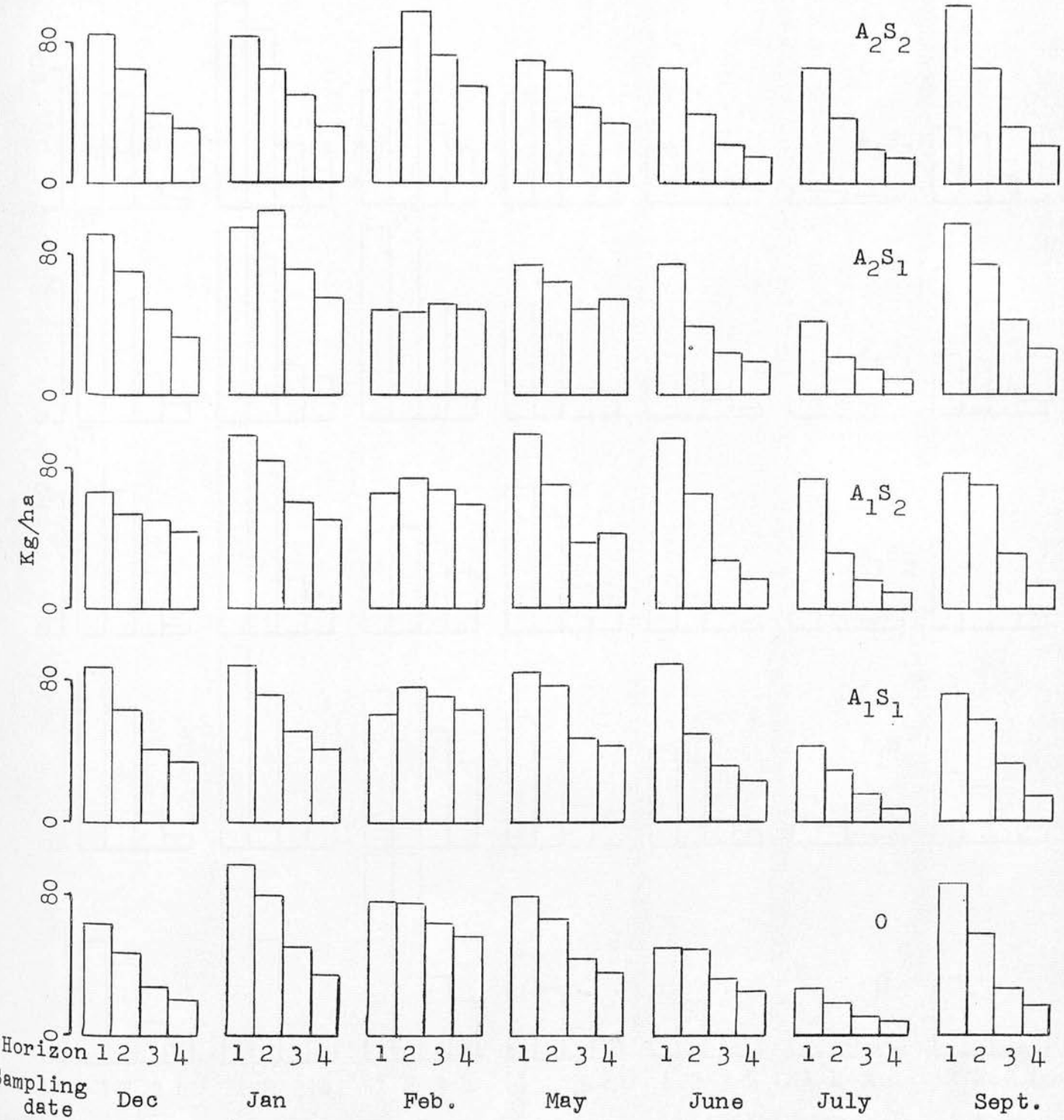


Fig. 10. Field Experiment: Contents of NO_3-N in soil horizons.

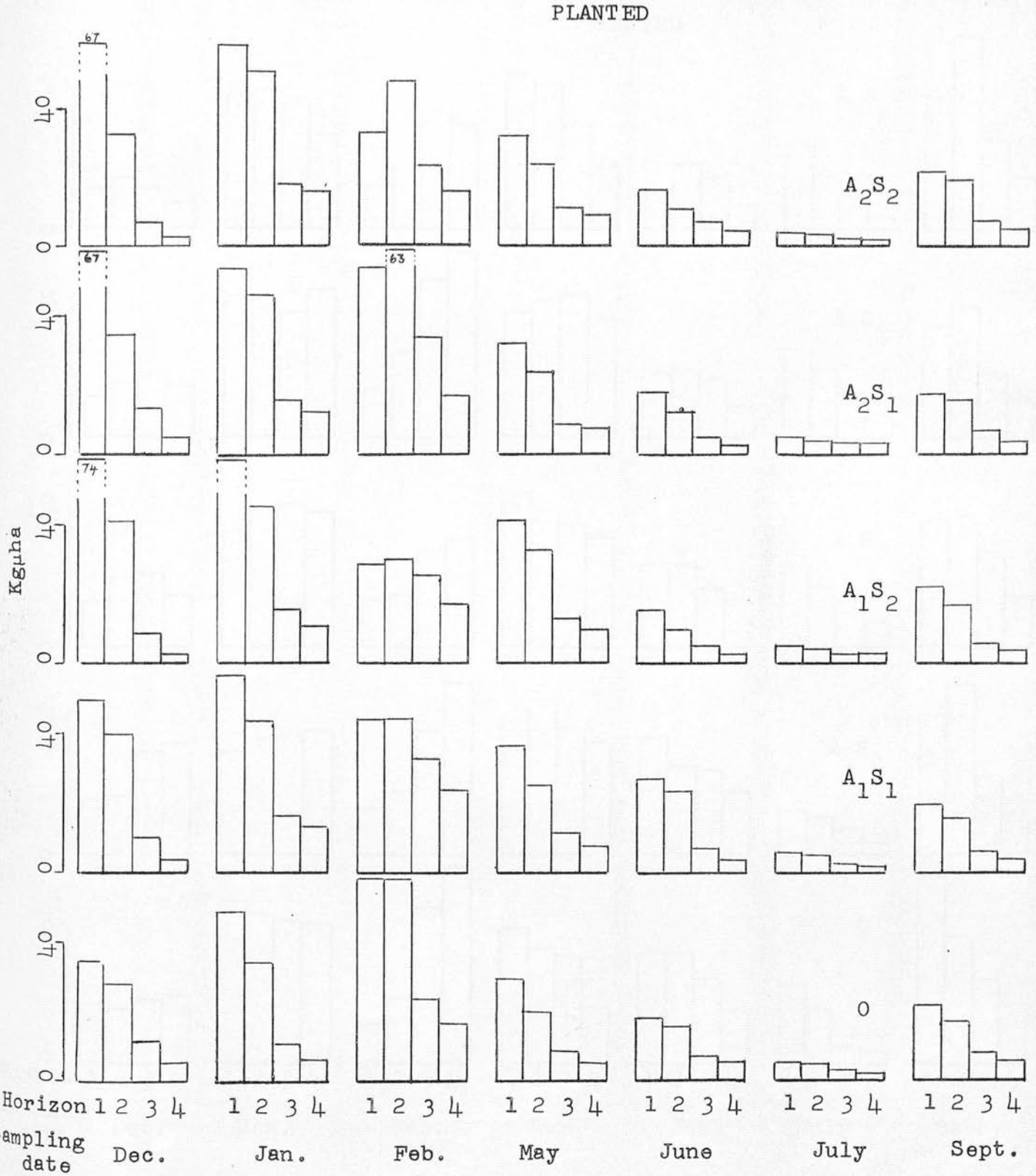


Fig. 11. Field Experiment: Contents of NH_4-N in soil horizons.

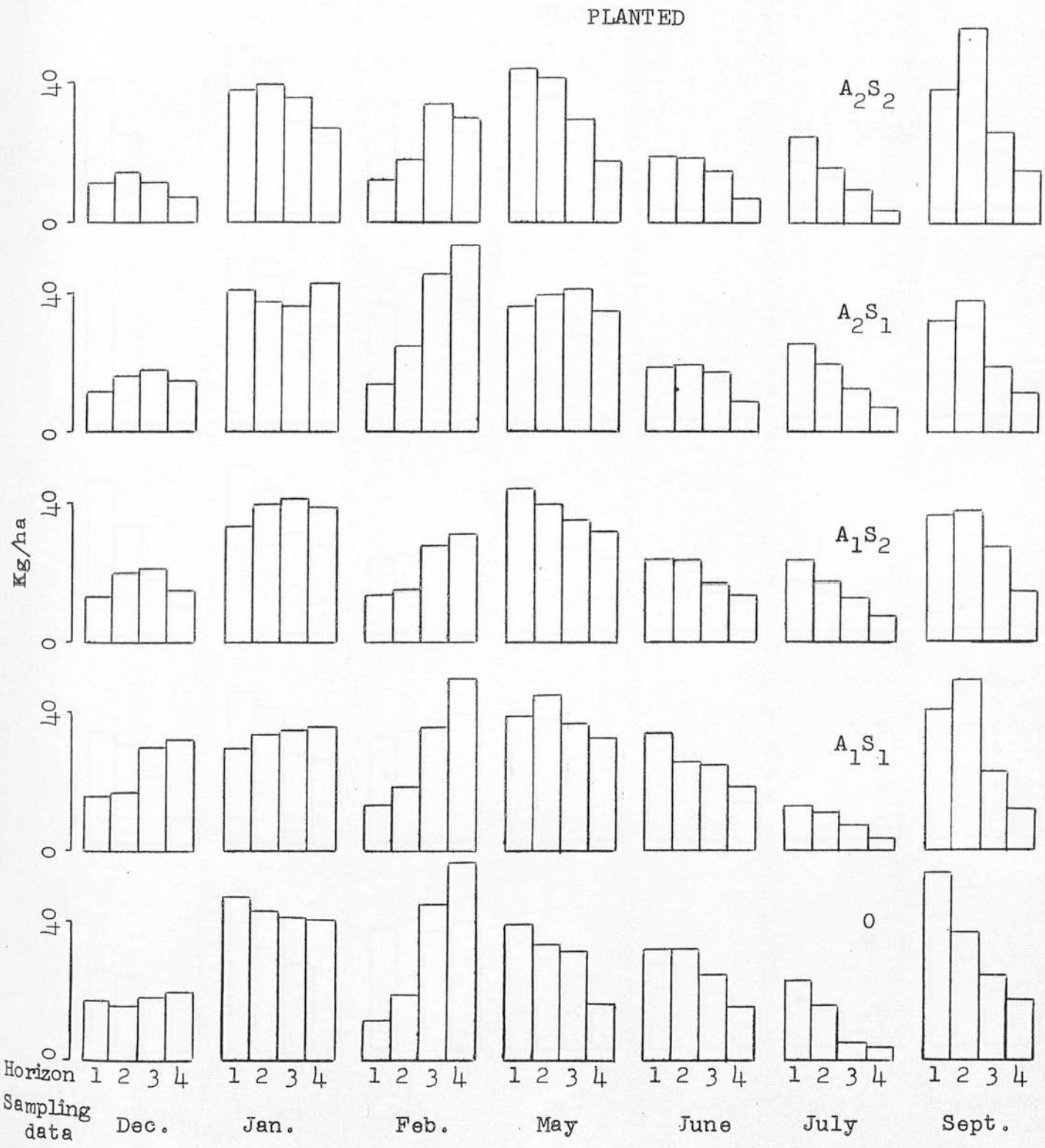


Fig. 12. Field Experiment: Contents of $(NO_3 + NH_4)N$ in soil horizons.

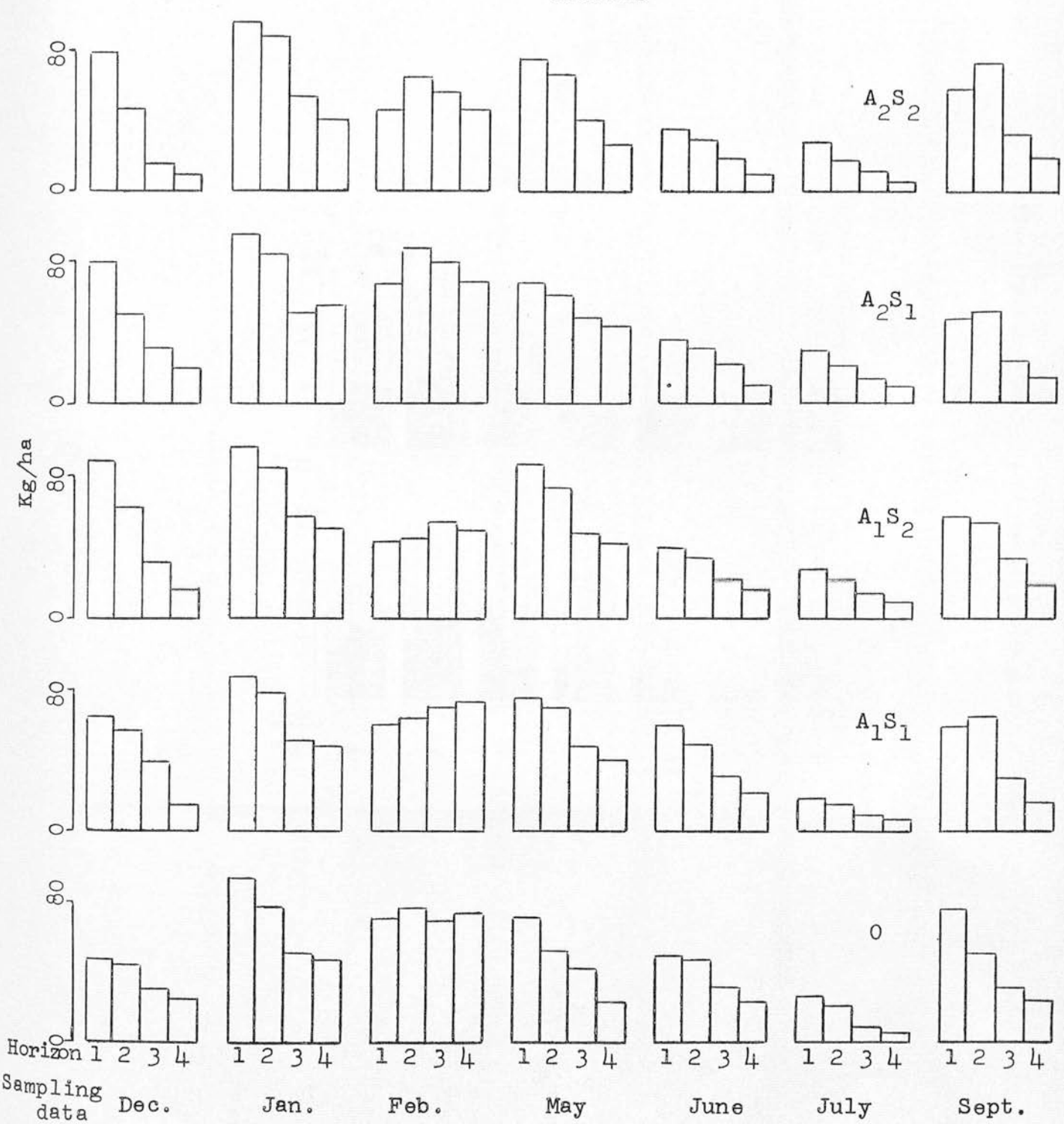


Fig. 13. Field Experiment: Contents of mineral N in soil profile.

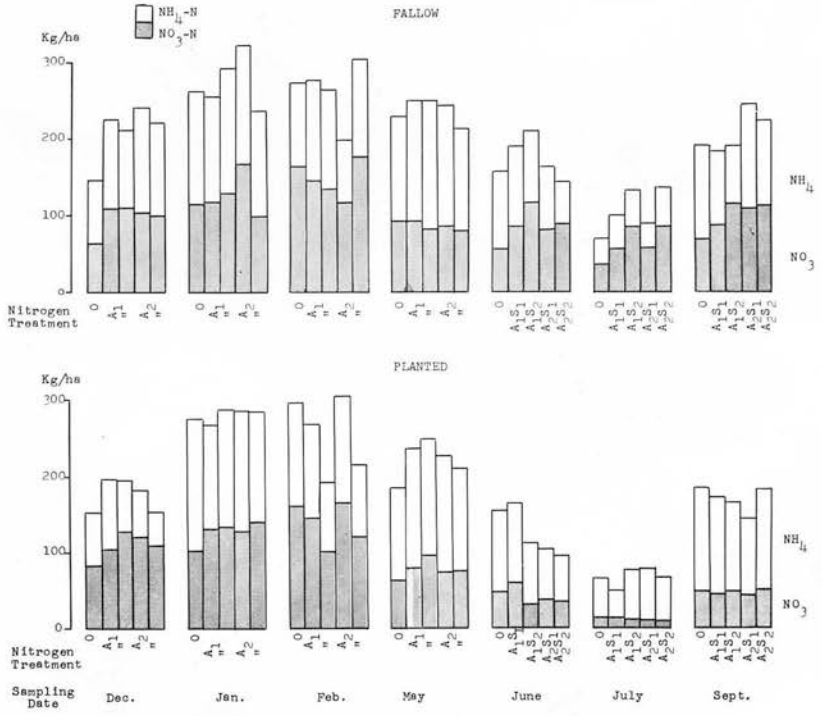


Fig. 14. Field Experiment: Contents of NO_3-N in horizons of fallow and planted soils.

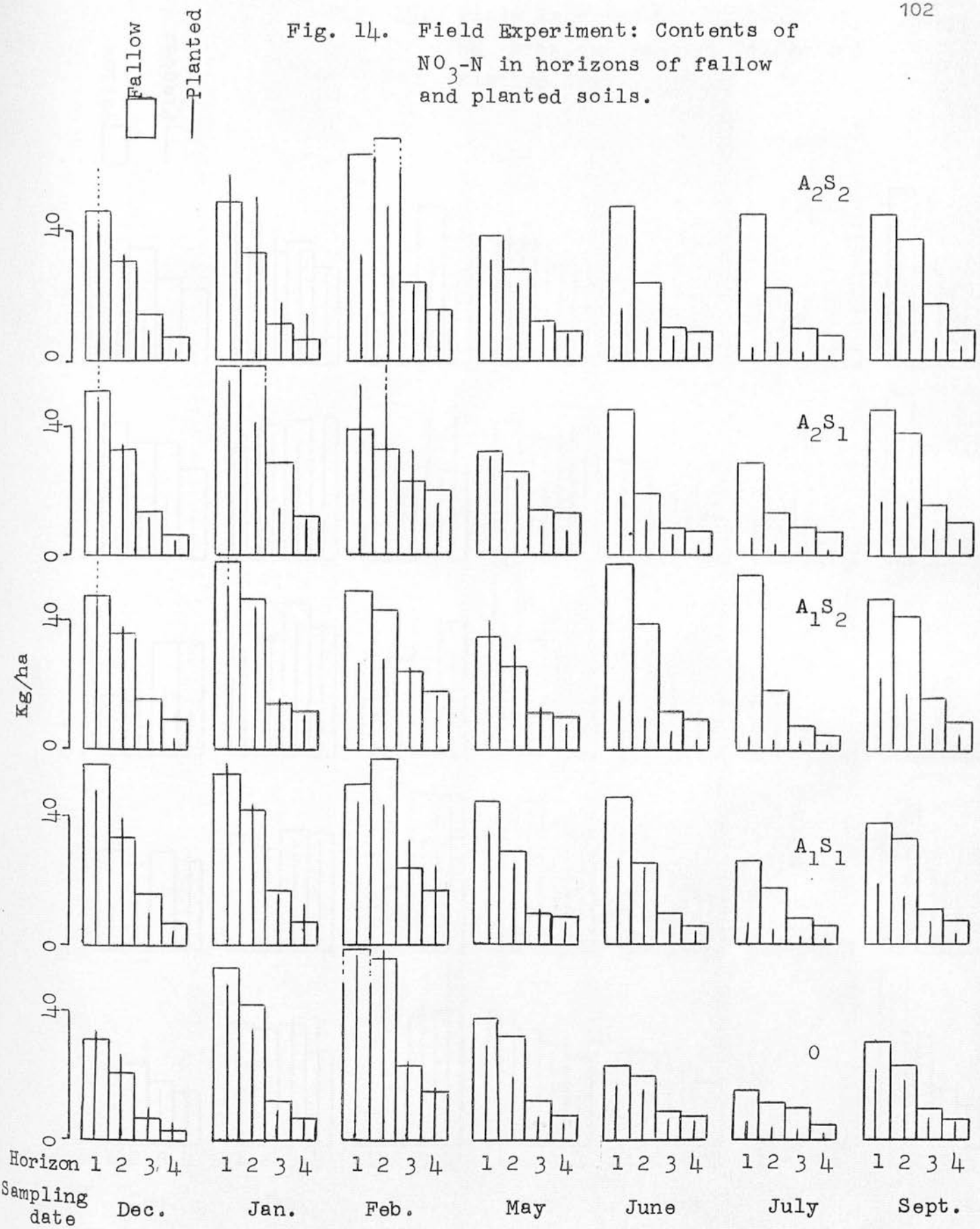


Fig. 15. Field Experiment: Contents of NH_4-N in horizons of Fallow and Planted soil.

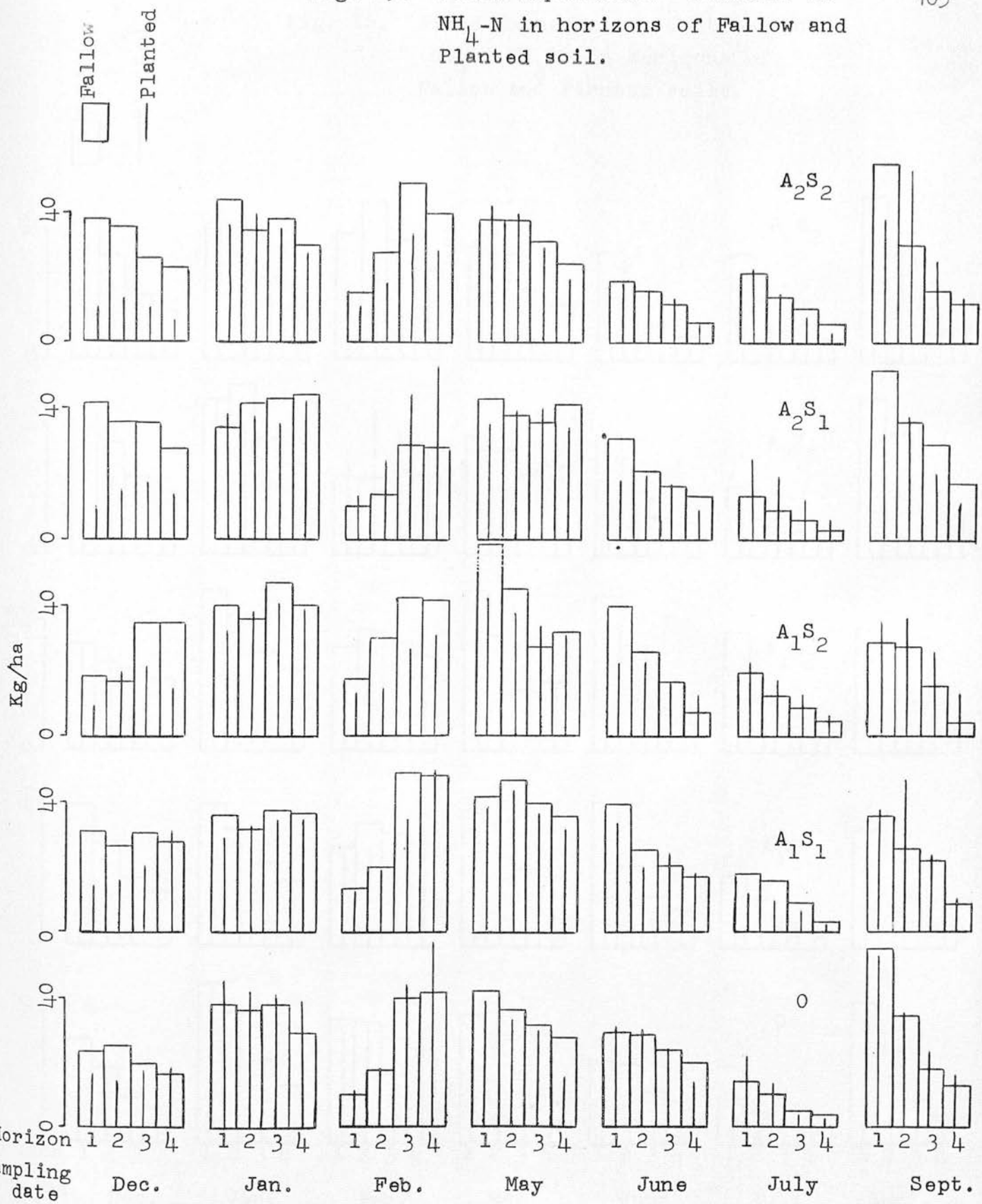


Fig. 16. Field Experiment: Contents of $(NO_3 + NH_4)N$ in horizons of Fallow and Planted soils.

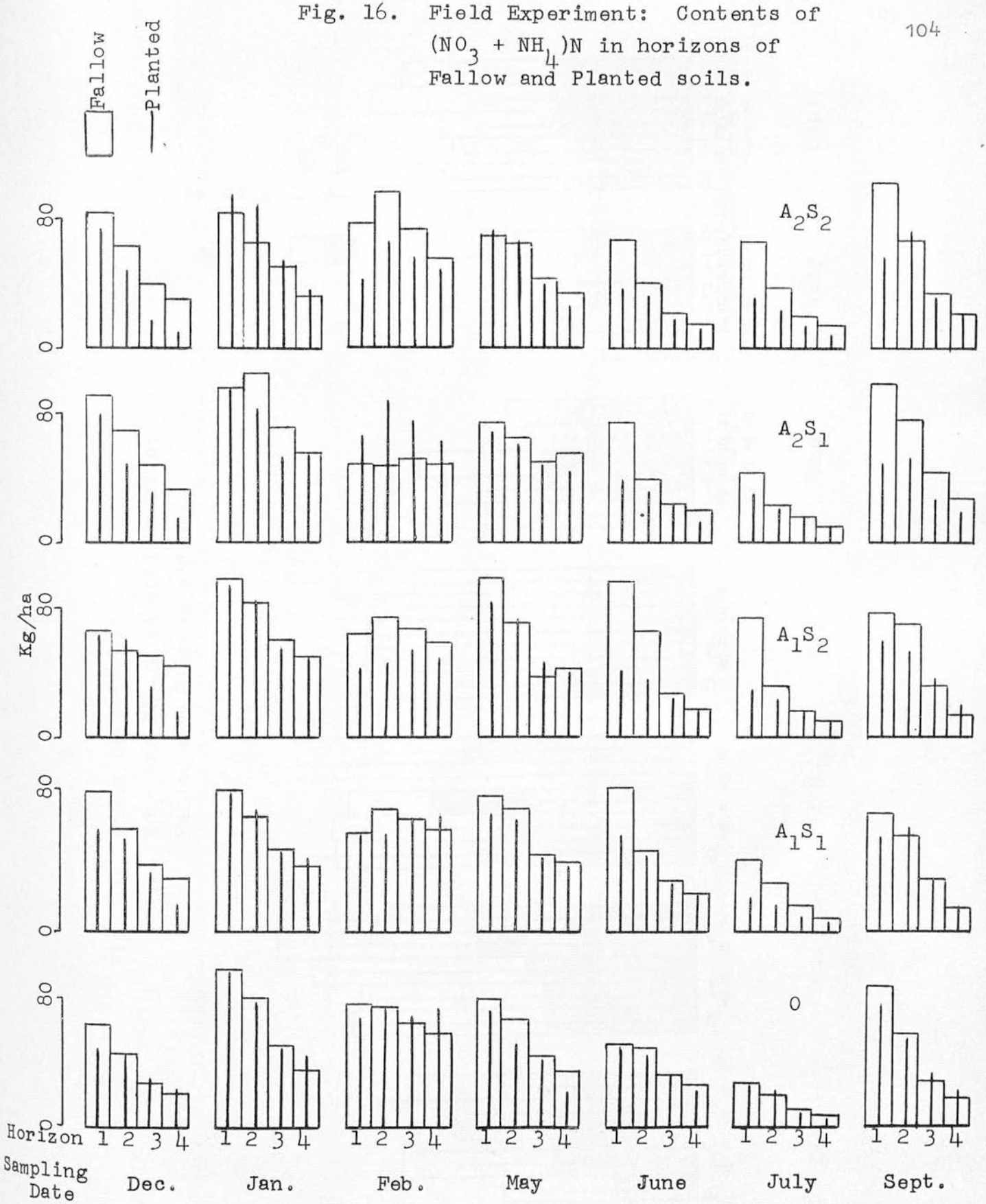


Fig. 17. Field Experiment:
NO_3- and NH_4- N in soil profile;
Fallow and Planted soils.

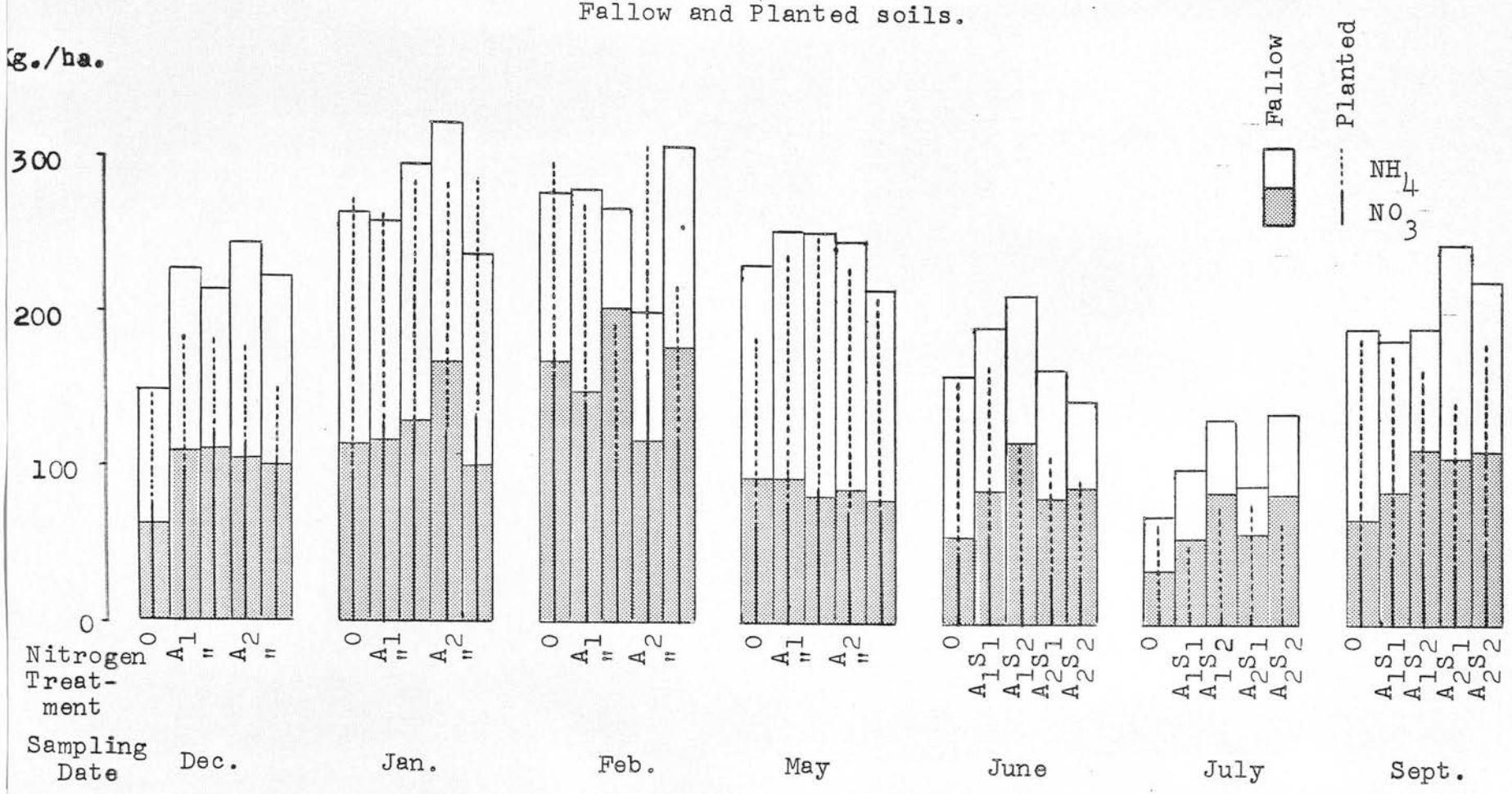


Fig. 18. Field Experiment: Seasonal Change in contents of mineral N in soil profile

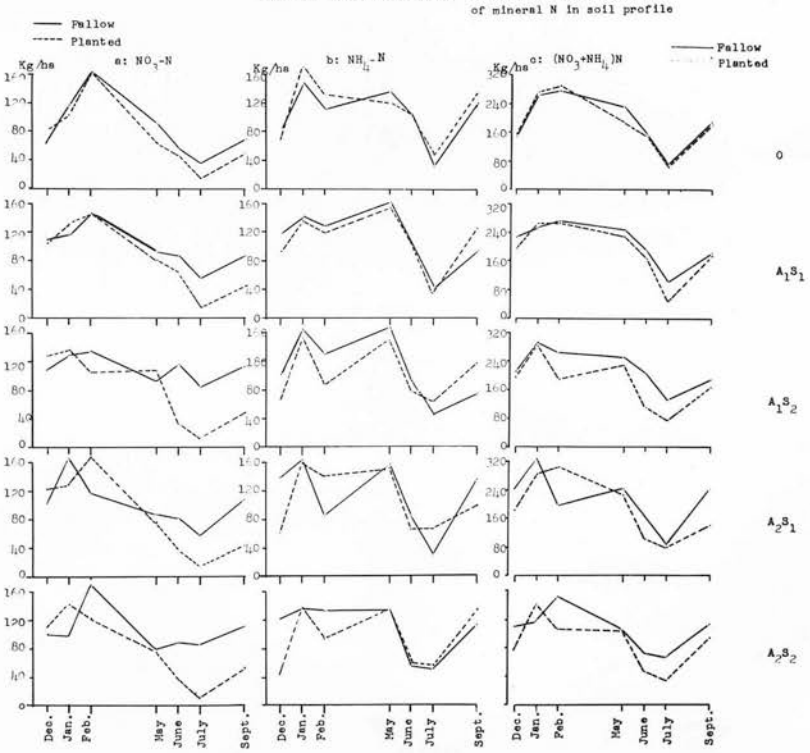


Fig. 19. Field Experiment.

N Uptake by plant.

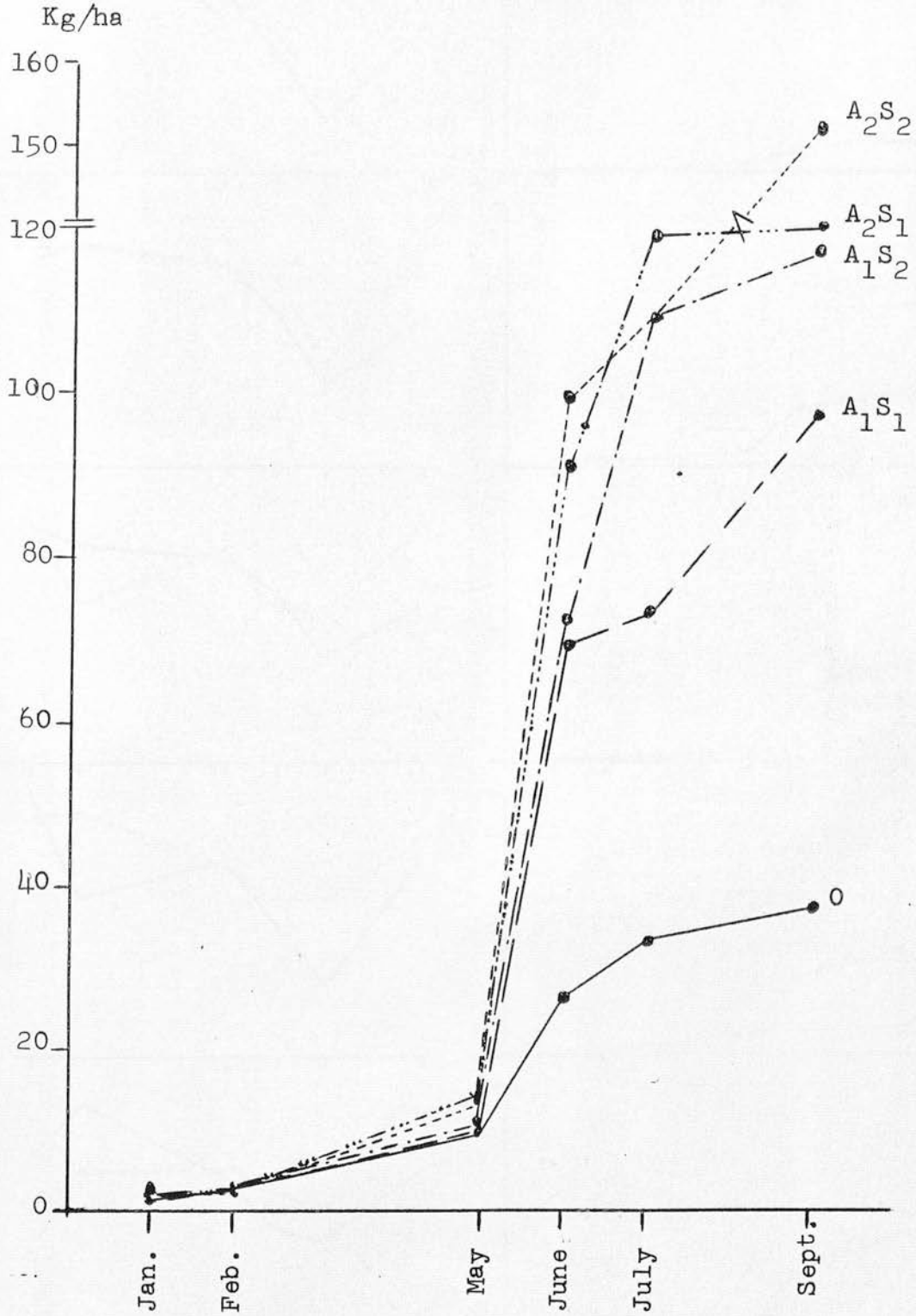


Fig. 20. Field Experiment:
Soil $(NO_3 + NH_4)N$ and N uptake

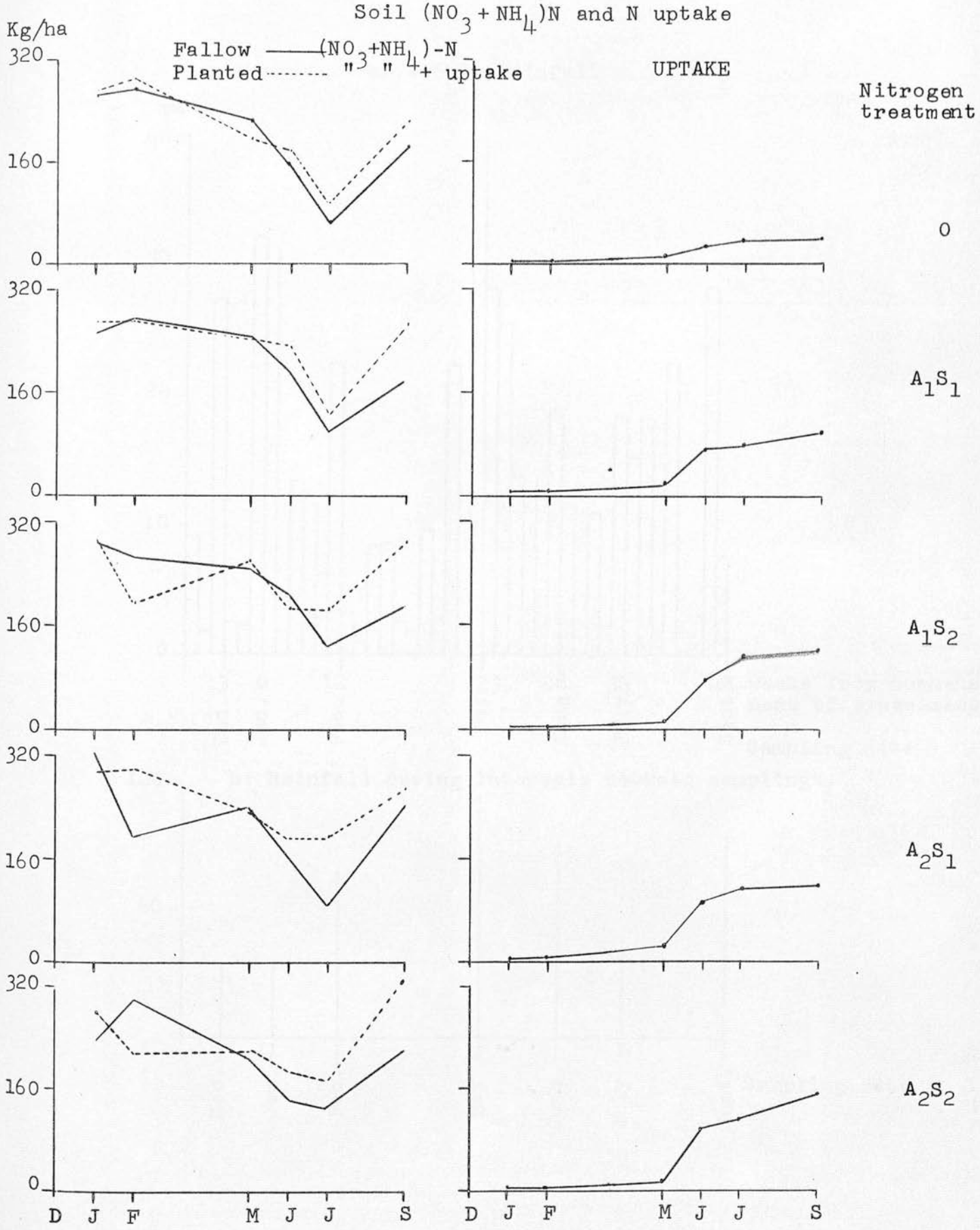
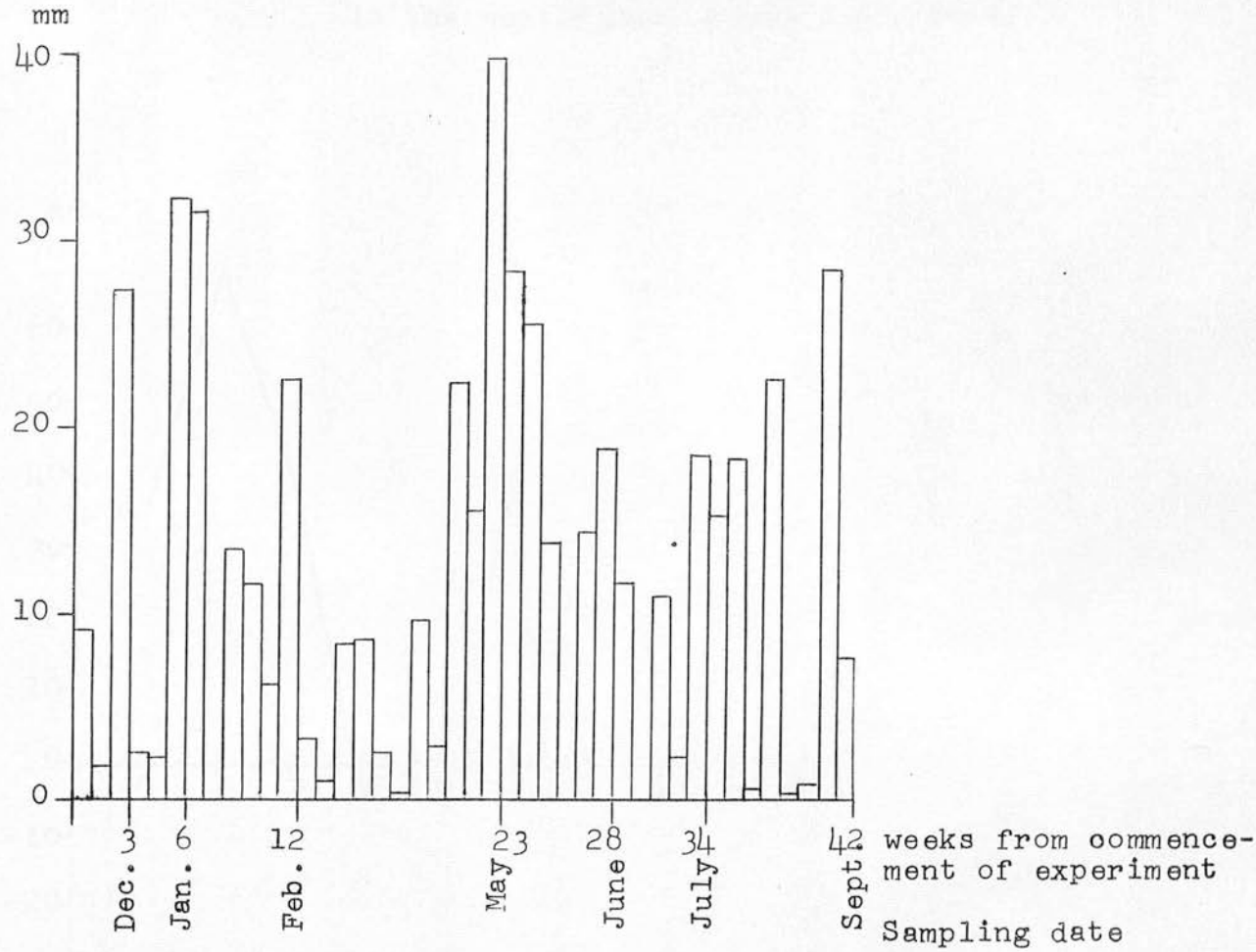


Fig. 21. Field Experiment

a: Weekly rainfall



b: Rainfall during intervals between samplings.

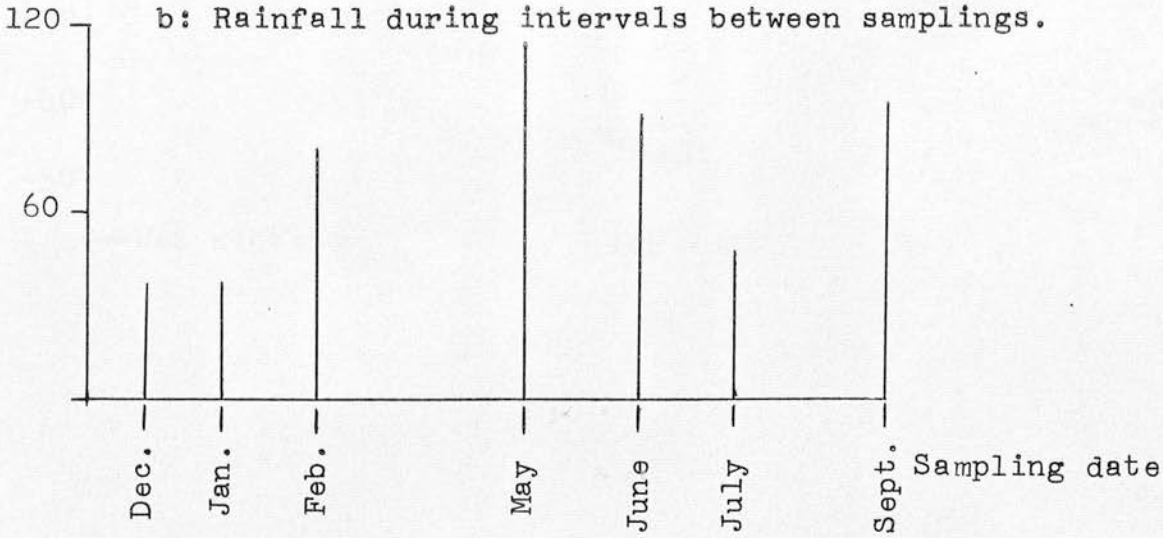
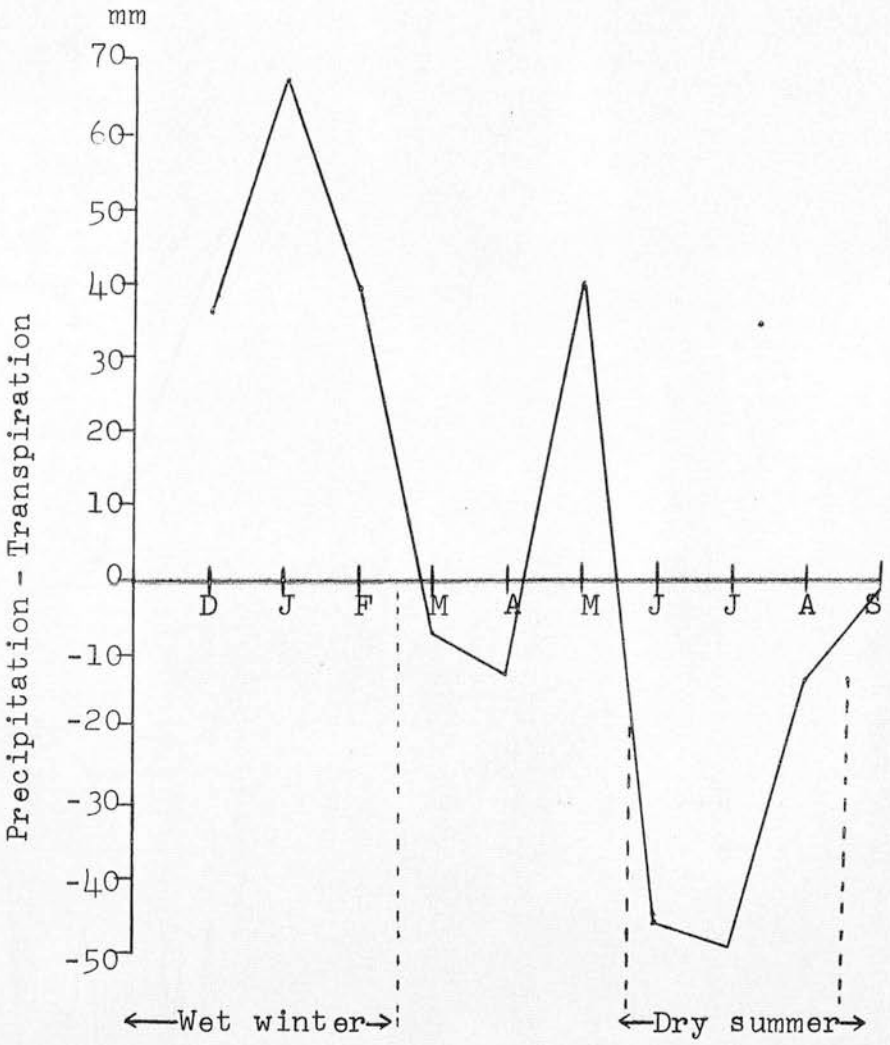


Fig. 21.

c: Precipitation - Transpiration
in the period Dec. 1968 - Sept. 1969.



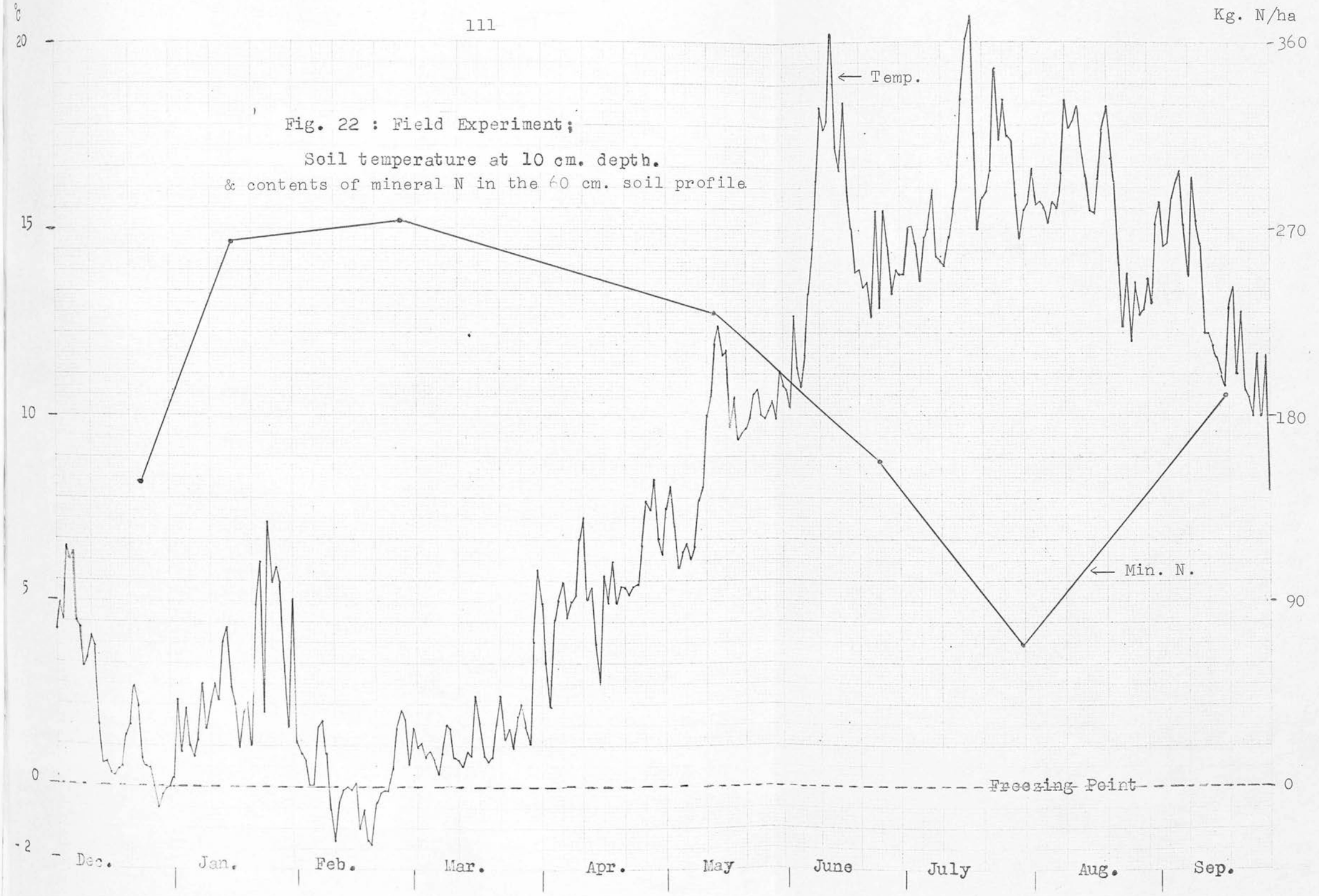


Fig. 22 : Field Experiment;

Soil temperature at 10 cm. depth.

& contents of mineral N in the 60 cm. soil profile

SECOND: GREENHOUSE EXPERIMENT I:

"Losses of fertiliser nitrogen from soil columns"

Contents:

- Dry matter yield of plant
- Mineral N in soil
- N uptake
- Leaching losses of mineral N
- Sum of (mineral N in soil + N removed by uptake and leaching)

DRY MATTER YIELD OF PLANT
(Fig. 23)

At all levels of watering, the plants grown in the topsoil yielded twice as much dry matter as those of the subsoil.

At the 5th week the unfertilised plants in the subsoil receiving R_2 and R_3 produced more D.M. than their fertilised counterparts, but at other times the application of fertiliser increased yield. In the topsoil there was a greater yield of dry matter when fertiliser was applied and this increase was greater in the topsoil than in the subsoil: the increases in the topsoil and subsoil were 14 and 4 per cent respectively.

Between the 3rd and 5th week, there was a 60 percent yield increase in the topsoil. However between the 5th and 7th weeks, a marked decrease (from 10 to 28%) occurred in all the no N and in the N R_3 treatments; the N R_1 and N R_2 topsoil treatments increased their yields slightly (1 - 5%). Plants grown in the subsoil underwent a progressive increase during the 3rd and 7th weeks except for N R_3 where a decrease occurred during the last two weeks of the experiment.

All the 3 water régimes produced similar yields on the 3rd week, but thereafter there were differences in yield associated with rates of watering: R_3 gave the smallest and R_2 gave the highest (Plate 12).

Plate 12: Greenhouse Experiment I:

Growth of grass in soil columns as affected by soil type and water régime (7th week of experiment)

R_1 R_2 R_3

Topsoil

R_1 R_2 R_3

Subsoil

MINERAL N IN SOIL DURING THE EXPERIMENT

The NH_4-N in the soil constitutes about one percent of the total mineral N; and for this reason the change in mineral N with time and treatment are largely due to the NO_3-N fraction.

The 'recovery of fertiliser N' referred to in this experiment is the result of subtraction of values of mineral N contents and plant uptake in the unfertilised treatments from those of the fertilised.

CONTENTS OF MINERAL N IN SOIL HORIZONS

(Fig. 24)

At each water régime there was an increase in the mineral N content with depth in both topsoil and subsoil. There was more N in the horizons of fertilised columns than unfertilised (Fig. 24a).

An inverse relationship exists between the amount of water applied and the mineral N content (Fig. 24b). The H_1 and H_2 of R_2 contained about 50% of the N in the corresponding R_1 horizons; the H_3 of both treatments had approximately the same content. The horizons in R_3 contained about one third the N in R_1.

Horizons of planted columns contained considerably less mineral N than the fallow (Fig. 24c). The planted horizons contained about 60 percent of the mineral N in the fallow horizons.

Between the 3rd and 5th week there was a decrease of 23, 19, and 30 percent in the mineral N content of H_1, H_2, and H_3 respectively (Fig. 24d). Between weeks 5 and 7, no change occurred

in either H_1 or H_2 but a small increase (12%) occurred in H_3.

Topsoil contained slightly greater mineral N than the subsoil (Fig. 24e), more so in H_3 than in H_1 or H_2. The H_3 of topsoil contained 33 kg. mineral N/ha and that of the subsoil 29 kg./ha.

CONTENTS OF MINERAL N IN SOIL COLUMN
(Fig. 25a)

Before commencement of experiment, soil mineral N was 47 and 24 kg. N/ha for topsoil and subsoil respectively. At the first sampling there was an increase in mineral N. Generally the planted soils contained smaller contents than the fallow.

Fallow

Contents and changes in mineral N:

As in individual horizons, there was a decrease in the contents of mineral N in soil columns with the increase in water régime.

While the mineral N increased with time in the R_1 treatment, particularly that of the topsoil, R_2 and R_3 caused a decrease in both topsoil and subsoil. The increase was much greater where no N was applied. On the other hand the decrease with R_2 and R_3 was greater where N was applied.

The decrease in the mineral N content with time was much smaller with R_3 (an average decline of 33 kg. N/ha between the 3rd and 7th week of the experiment) than with R_2 (an average decline of 77 kg. N/ha).

Contents and changes in fertiliser N:

More mineral N was present in the fertilised soil than in the unfertilised throughout the experiment, indicating a retention of fertiliser N by the soil. The amount of fertiliser N (as mineral N)

decreased with time in the topsoil in both R_1 and R_2 but remained nearly constant in the subsoil with these two water régimes. With R_3 there was little fertiliser N left (only 22%) at the first sampling and very little (8%) at the end of experiment.

Soil type and retention of fertiliser N:

The difference in retention of fertiliser N (as (NO_3+NH_4)-N) by the two soils was shown by the R_1 and R_2 treatments: at the first sampling (3rd week) all of fertiliser N was still present in the topsoil columns but only 30 - 50% was retained by the subsoil ones. At the end of the experiment the topsoil retained 12 - 30% whereas the amount retained by the subsoil hardly changed.

In R_3 there was little difference in the amounts of fertiliser N retained by the two soils.

PLANTED

Contents and changes in mineral N:

There was little change in the mineral N contents of the columns on increasing the soil moisture from R_1 to R_2 at each sampling date. Increasing the moisture content to R_3 resulted in a decrease in the contents of mineral N compared with R_1. At each water régime mineral N decreased with time.

Contents and changes in fertiliser N:

As in fallow columns, fertilised treatments contained - in general - more mineral N than the unfertilised, but there was a decrease in 'fertiliser N' retained by soils with time. This decrease was greater in R_1 than R_2 or R_3 and in topsoil than in subsoil.

Soil type and retention of fertiliser N:

28% of fertiliser N was retained by the R_1 topsoil on the 3rd week and a similar amount on the 5th week, but none (due to an increase in mineral N of the no N treatment) on the 7th week. With R_2 the same soil retained 18% of 'fertiliser N' on the 3rd week and 15% at the end of experiment; with R_3 30% was retained at the first sampling and none at the end of experiment. The subsoil showed a similar pattern, but the amount of fertiliser N retained was greater than that retained by the topsoil particularly at R_1 and R_2 water régimes and during the first 5 weeks of the experiment. This is illustrated by the retention of 60% of fertiliser N on the 5th week by the R_2 subsoil treatment as compared with none retained by its topsoil counterpart. There was no difference between the two soils at R_3 water régime.

N UPTAKE
(Fig. 25b)

Plants grown in the topsoil removed nearly twice as much N as those in the subsoil throughout the experiment. There was a highly significant increase in N uptake in the topsoil due to the application of fertiliser N but none in the subsoil. This occurred throughout the experiment with R_1 and R_2, but with R_3, however, the greater uptake from the fertilised columns lasted for the first 5 weeks, after which the uptake from both the N and no N treatments was similar. The percentage recovery of fertiliser N from the topsoil on the 3rd week was 72 and 65 with R_1 and R_2 respectively; 34 and 43 on the 5th week, and 52 and 68 on the 7th week. With R_3, the figures were 56, 50, and 2 at each of the three sampling dates respectively.

Effect of watering:

Treatments of R_1 and R_2 allowed similar quantities of N to be removed by plant, but R_3 caused less N to be removed than either R_1 or R_2; this difference was greater in the topsoil than in the subsoil, and also increased with time. While 6 and 13 Kg. N/ha more were removed by R_1 and R_2 over R_3 respectively on the first sampling by topsoil-plants, the comparable figures at the last sampling (7th week) were 51 and 47 Kg. N/ha.

Time and N uptake:

There was an increase in the amount of N removed by plant uptake throughout the 7 weeks of this experiment except for N R_3 where an increase in N uptake occurred until the 5th week after which there was a decrease of 30 and 7 Kg. N/ha for fertilised topsoil and subsoil respectively.

LEACHING LOSSES OF MINERAL N
(Fig. 25c)

The following results are from the R_3 treatment since this was the only régime which allowed leaching to occur. The mineral N lost by leaching was 98 - 99% NO_3-N.

Effect of fertiliser:

At each sampling, more mineral N was lost from fertilised treatments than from unfertilised ones.

Fallow:

Even at the first sampling, the difference between fertilised and unfertilised columns was substantial. At this time 75 and 100 percent of applied N had been leached from the topsoil and subsoil respectively. During the next 4 weeks (i.e. from 3rd to 7th week) there was no further loss of fertiliser nitrogen.

Less fertiliser N was lost from the topsoil than from the subsoil at each sampling.

Planted:

During the experiment, twice as much mineral N was lost from the fallow as from the planted columns in both the N and no-N treatments. The percentage loss of fertiliser N from the planted columns was small during the first 5 weeks: the topsoil and subsoil lost 18 and 32 percent respectively of fertiliser N. Between the 5th and 7th week, the percentage loss rose to 80 and 92 percent from topsoil and subsoil respectively.

SUM OF (MINERAL N IN SOIL + N REMOVED BY UPTAKE AND LEACHING) (Fig. 26)

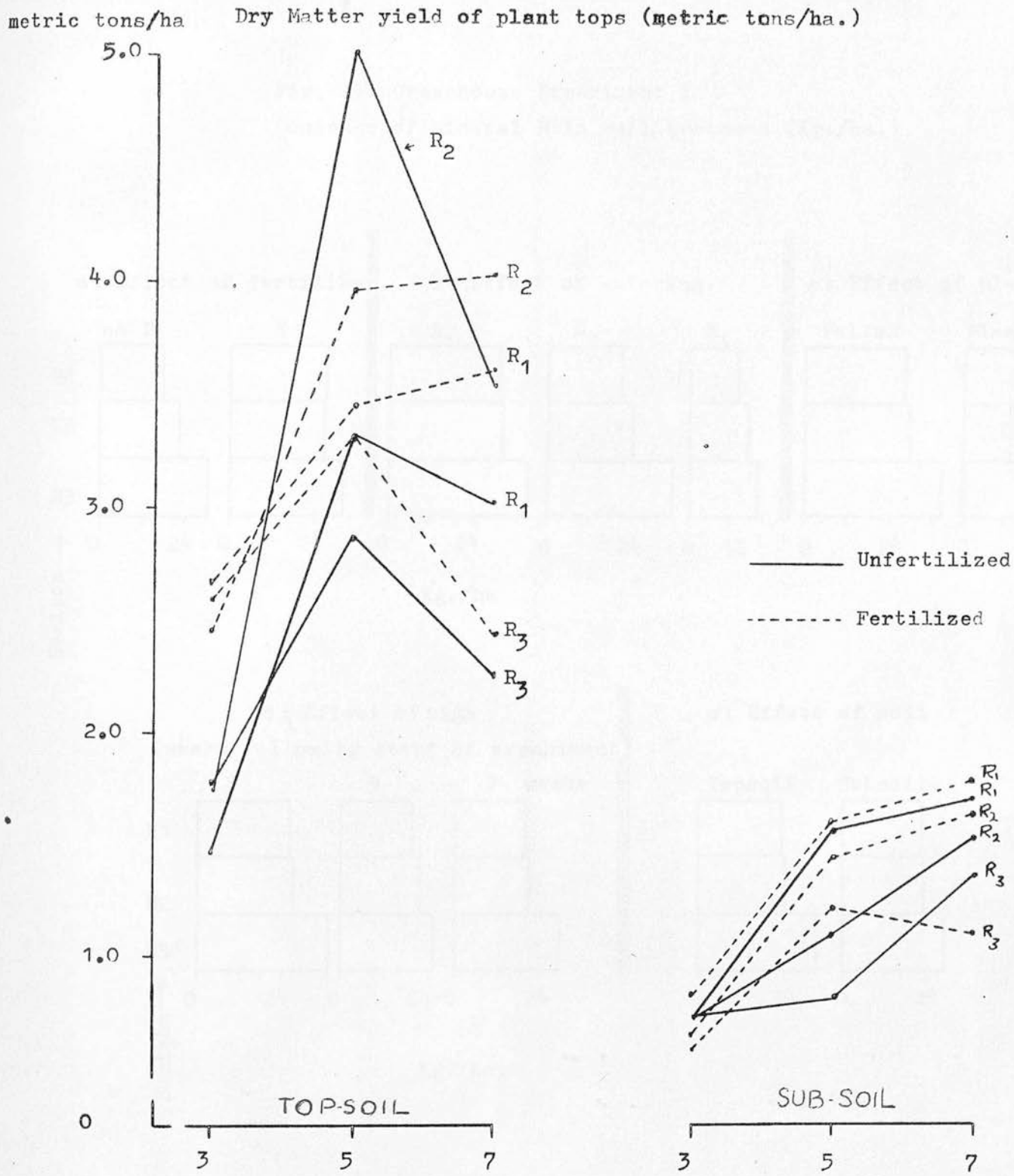
Summation of (i) the contents of mineral N in soil column + (ii) N removed by plant (where applicable, i.e. planted soil) + (iii) mineral N lost by leaching (where applicable, i.e. R_3 treatments) was investigated at each sampling date. The apparent recovery of fertiliser N at any of these sampling dates is the difference between the summation of these values (i + ii + iii) of the N and that of the no-N treatments.

The summation for topsoil was greater than that for the subsoil, and was also greater in planted than fallow soils,; and where leaching was allowed (R_3) than where it was not permitted (R_1 and R_2).

Apparent recovery of fertiliserN:

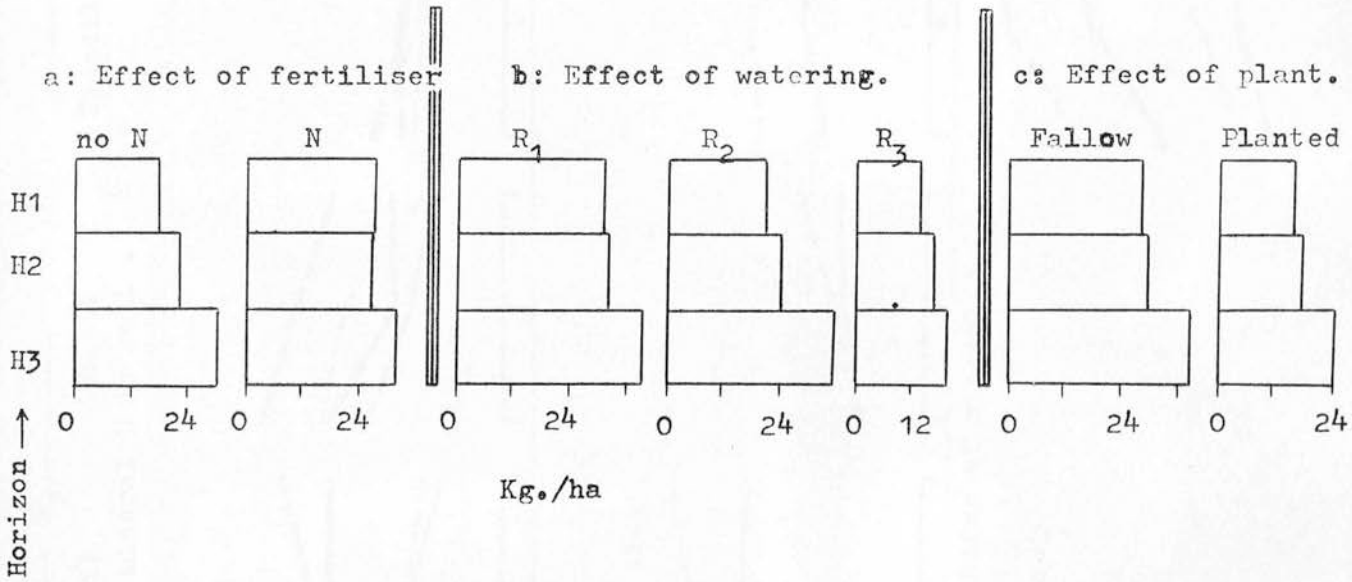
The amount of fertiliser N recovered with R_1 and R_2 remained fairly constant throughout the experiment when the soil was planted, but decreased with time where the soil was fallow. On the other hand, with R_3, both fallow and planted soils showed a similar recovery of fertiliser N throughout the experiment.

Fig. 23 . Greenhouse Experiment I :
Dry Matter yield of plant tops (metric tons/ha.)



weeks following commencement of experiment .

Fig. 24. Greenhouse Experiment I :
Contents of mineral N in soil horizons (Kg./ha.)



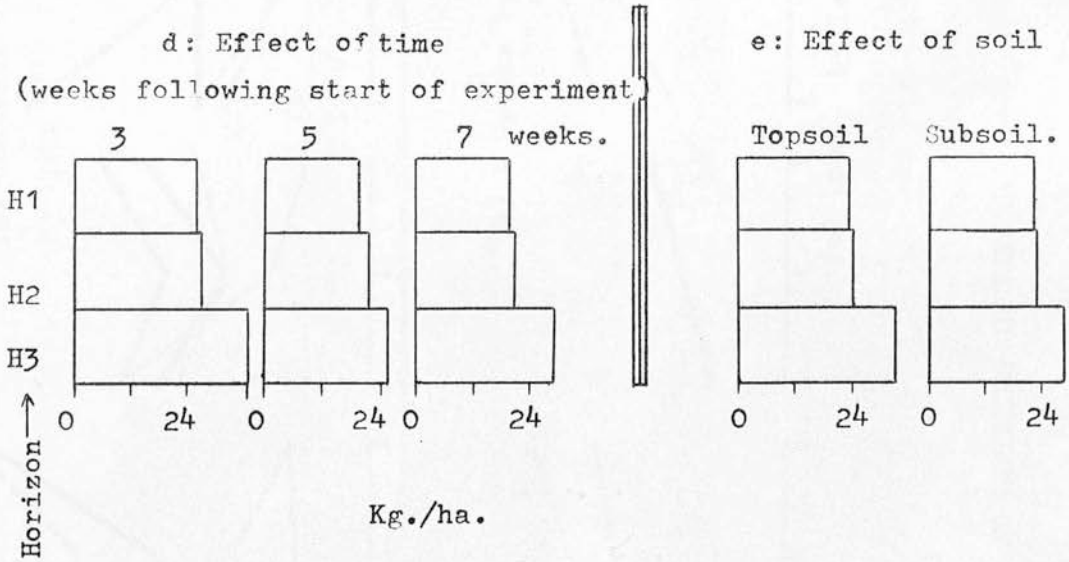


Fig. 25 : Greenhouse Experiment I :

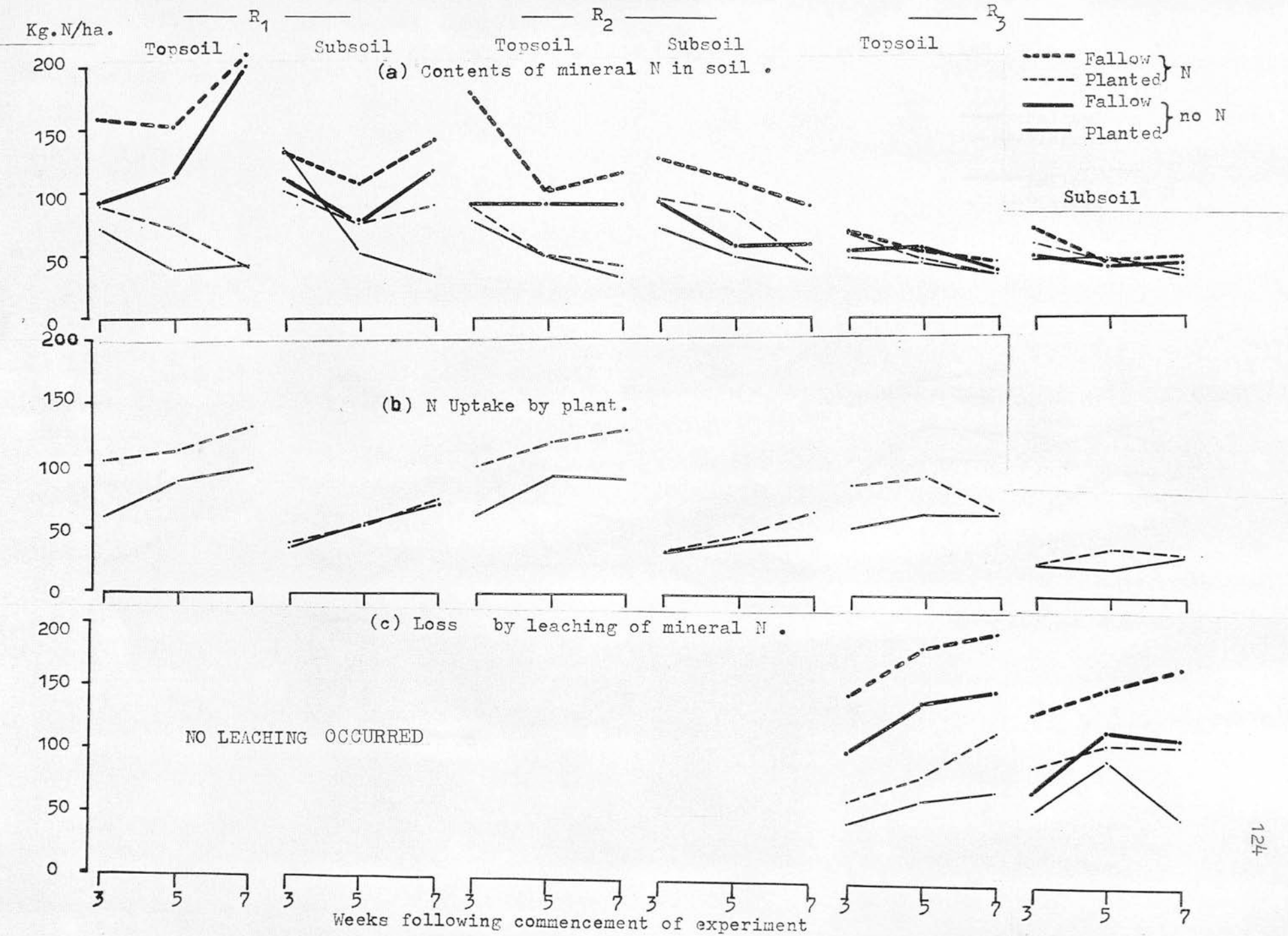
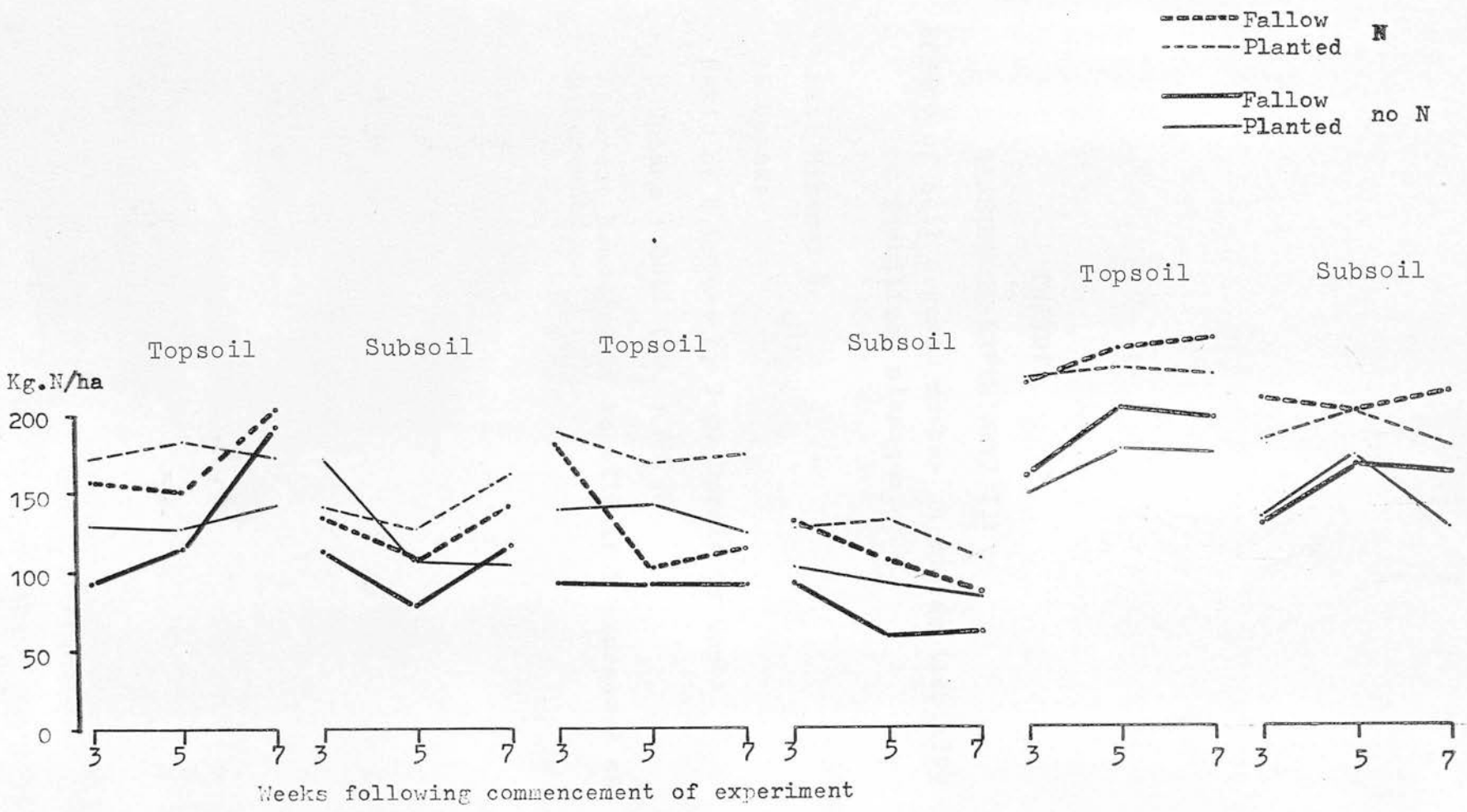


Fig. 26: Greenhouse Experiment I:
Sum of a mineral N in soil + N uptake + mineral N in leachate



THIRD:

GREENHOUSE EXPERIMENT II:

Effect of soil organic matter on the availability of fertilizer nitrogen.

- Soil Mineral N
- N Uptake
- Ratio of N Uptake by Tops/Uptake by Roots
- N Uptake + Soil (NO_3 + NH_4)N
- Apparent Recovery of Fertilizer N expressed as a percent.

SOIL MINERAL N (Fig. 27)
(at the end of the experiment)

Fallow Soil (Fig. 27a)

Taking the average over the 3 levels of N there was 25% more NO_3-N in the unignited soil than in the ignited at the end of experiment. On the other hand, the NH_4-N contents were lower in the unignited than in the ignited soil. Consequently, there was little difference in the (NO_3 + NH_4)N contents of the 2 soils.

Fertilized soils contained far more NO_3 and (NO_3 + NH_4)N than unfertilized and the difference increased with increase in the N rate. With NH_4-N, on the other hand, there was little difference between the 3 N-treatments, in either soil.

Planted Soil (Fig. 27b)

The difference between the two soils and between the N treatments was not statistically significant. This applies to both forms of N (i.e. NO_3-N and NH_4-N)

N UPTAKE (Fig. 28)

The application of fertilizer N significantly increased N uptake by roots and tops on each of the 2 soils.

The small increase in uptake by plant tops from the unignited soil compared with that from the ignited (at each level of N) was not statistically significant. However, the roots in the unignited soil removed a significantly greater amount of N than those grown in the ignited

soil. Thus the N removed by (tops + roots) from the unignited soil was significantly greater than that from the ignited.

RATIO OF N UPTAKE BY TOPS/UPTAKE BY ROOTS (Fig. 29)

This ratio ranged from 1:1 to 2·8:1 and increased with increase in the rate of N and was greater in ignited than in unignited soil.

N UPTAKE + SOIL (NO_3 + NH_4)N (Fig. 30)

Although there was much more (NO_3 + NH_4)N in the fallow soil than in the planted soil at the end of the experiment, (Fig. 27), N uptake by plants (Fig. 28) more than offset this difference and as a result the (N uptake + soil NO_3 + NH_4-N) in the planted system (Fig. 30b) was far greater than the soil (NO_3 + NH_4)N in the fallow system (Fig. 30a).

In the planted system, there was much more (mineral + uptake)N in the unignited than in the ignited soil at each level of N(N_0, N_1, and N_2). However, this difference was not statistically significant. The increase in the rate of N increased the amount of (mineral + uptake)N.

APPARENT RECOVERY OF FERTILIZER N EXPRESSED AS A PERCENT (Fig.31)

The percent apparent recovery of fertilizer N was calculated as follows:

a) Fallow: $$\frac{\text{Soil}(NO_3 + NH_4) \text{ with N} - \text{Soil}(NO_3 + NH_4) \text{ without N}}{\text{amount of N applied}} \times 100$$

b) Planted:

$$\frac{(\text{N uptake+soil } NO_3\text{+}NH_4)\text{with N} - (\text{N uptake+soil } NO_3\text{+}NH_4)\text{without N}}{\text{amount of N applied}} \times 100$$

Recovery of applied N in the planted systems was far higher than in the fallow and, on average, recovery appeared to increase with increase in fertilizer rate. The unignited soil gave a slightly higher recovery than the ignited soil, taking the average of the 2 rates of N.

Plate 13 GREENHOUSE EXPERIMENT II

Top and Root Growth

S_1: ignited soil S_2: unignited soil.

Plate 14 Greenhouse Experiment II
Growth of ryegrass at the 40th day.

ignited unignited ignited unignited ignited unignited

N_0 N_1 N_2

Fig. 27. Greenhouse Experiment II:
contents of NO_3^- and NH_4-N in soil
(mg/pot)

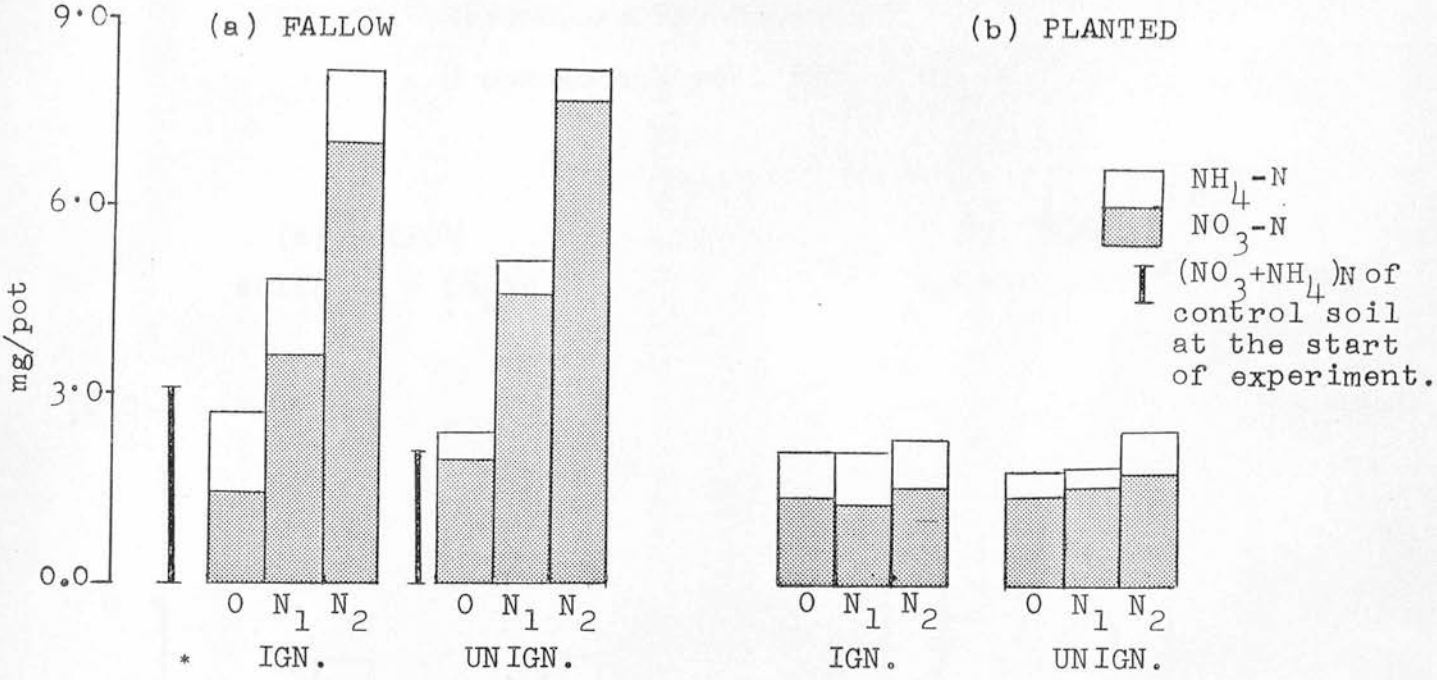
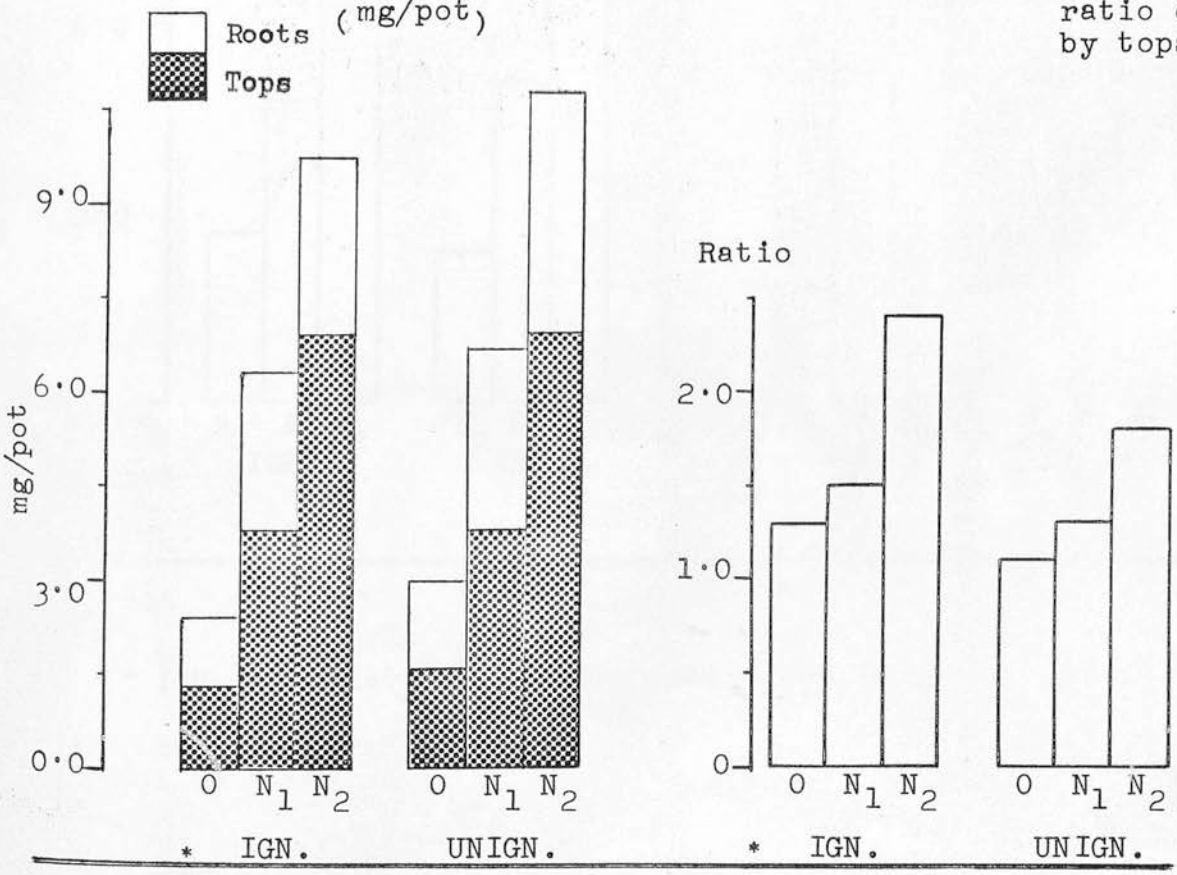


Fig. 28. Greenhouse Experiment II:
N uptake
(mg/pot)

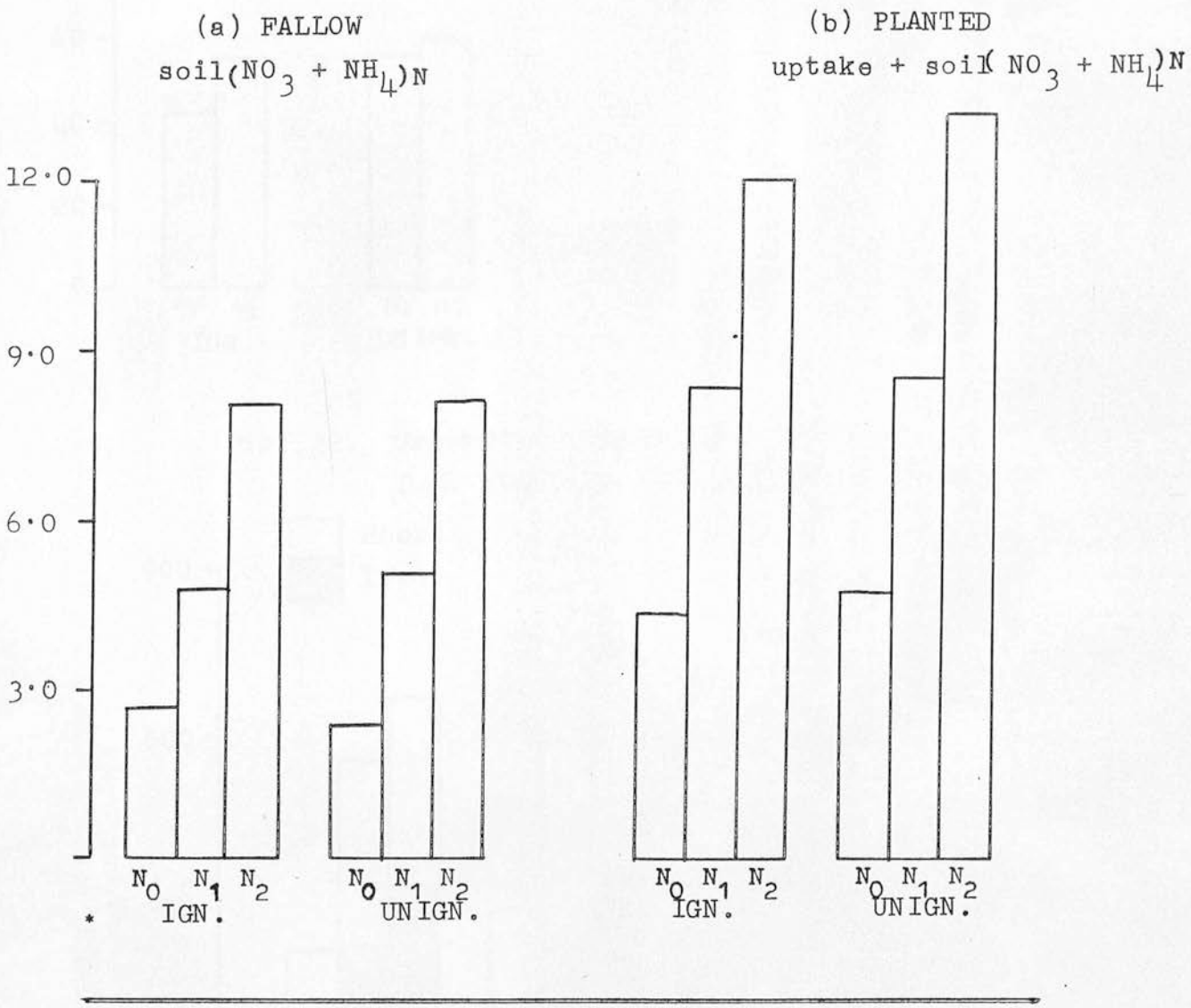
Fig. 29: Greenhouse Experiment II:
ratio of N uptake by tops/roots



* IGN. : ignited soil ; UNIGN. : unignited soil.

Fig. 30. Greenhouse Experiment II.

N uptake and soil (NO_3 + NH_4)N



* IGN. : ignited soil ; UNIGN. :unignited soil.

Fig. 31. Greenhouse Experiment II:
apparent overall recovery

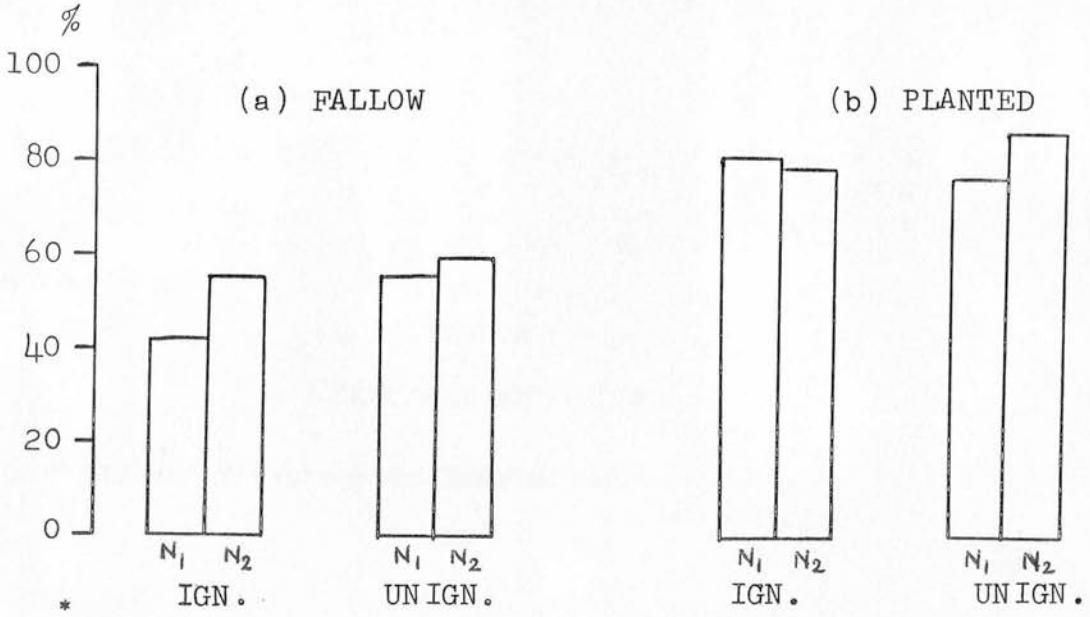
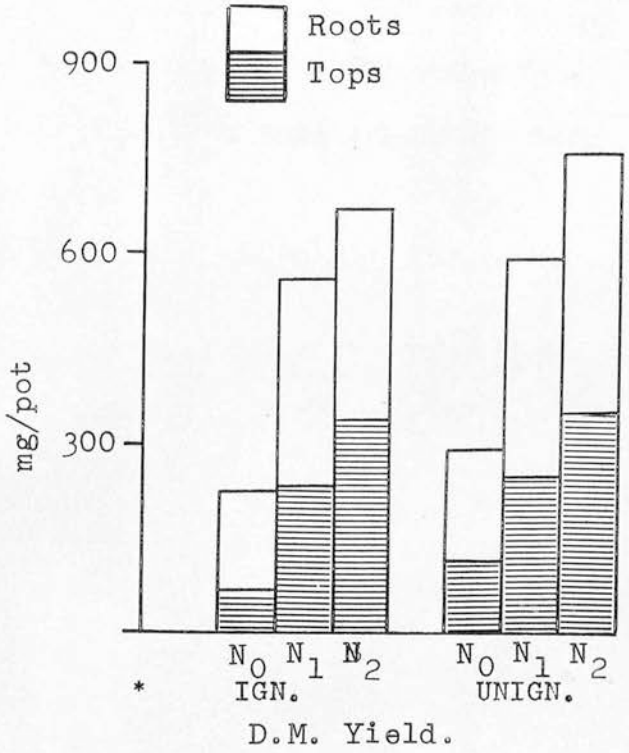


Fig. 32. Greenhouse Experiment II:
D.M. yield of tops and roots of plant.



* IGN.: ignited soil; UNIGN. : unignited soil.

FOURTH :

LABORATORY EXPERIMENT:

" Effect of Aggregates Size on Leaching Loss of NO_3-N "

Contents:

. Soil

1. The rate of percolation.

2. Leaching loss of N.

. Sand : Leaching loss of NO_3-N.

A: SOIL

1. The rate of percolation (Fig. 33):

The following are the results of a small investigation the object of which was to assess the rate of percolation through aggregates kept at water-holding-capacity (W.H.C.) moisture content.

The pattern of percolation of water through columns of large and of small soil aggregates was different, but the time taken for 14 ml. of water to pass through each aggregate size was almost the same (about 180 sec.). The 1 ml. deficit was probably lost through evaporation. The difference was in the pattern of flow: while percolation through the small aggregates remained fairly steady throughout the experiment (0·7 ml. s^{-1}), the rate was much greater (3·9 ml. s^{-1}) during the first 30 sec. in the large aggregates, dropping rapidly to 0·1 ml. s^{-1}. About 80 percent of the added water passed through the large aggregates in 30 sec. but it took five times (150 sec.) as long for a similar proportion (83%) to pass through the small aggregates.

2. Leaching loss of N (Table 7 , Fig. 34a):

Since the quantity of NH_4-N in the leachate was only 15% of the total mineral N removed, the pattern of leaching followed that of the NO_3-N.

NO_3-N:

At each of the first 4 leachates, the small fertilised aggregates

gave up more NO_3-N than the large ones but the reverse occurred during each of the remaining 6 leachates and the total loss was slightly less from the small aggregates. In the unfertilised columns the small aggregates consistently lost more NO_3-N throughout the experiment.

NH_4-N:

Although NH_4-N was not applied, the leachates from the fertilised columns contained nearly four times as much NH_4-N as their unfertilised counterparts at the end of the experiment. In both fertilised and unfertilised treatments small aggregates consistently lost more NH_4-N than the large ones.

3. Apparent recovery of fertiliser N (Table 7):

At the end of the experiment, the NO_3-N in the leachate from fertilised in excess to that from the unfertilised columns was about 99 percent of that applied.

4. Soil NO_3-N and NH_4-N (Table 7):

At the start of the experiment, each soil contained ·150 mg. NO_3-N and ·290 mg. NH_4-N. On the addition of 29·20 mg. fertiliser NO_3-N each fertilised column contained, theoretically, 29·35 mg. NO_3-N.

At the end of the experiment, the NO_3-N content of the control was almost double what it was at the beginning. Fertilised and unfertilised columns contained similar quantities of NO_3-N, but there was more NH_4-N in the fertilised ones.

In both treatments, small aggregates contained more NH_4-N than large aggregates.

Table 7; Laboratory Experiment

$(NO_3 + NH_4)N$ in soil and in leachates.

	No N			N		
	N(mg. per tube)			N(mg. per tube)		
(a) Before leaching	NO_3	NH_4	$NO_3 + NH_4$	NO_3	NH_4	$NO_3 + NH_4$
Small and large aggregates.						
Soil	0·15	0·29	0·44	0·15	0·29	0·44
Fertiliser	nil	-	-	29·20	nil	29·20
Soil + Fertiliser	0·15	0·29	0·44	29·35	0·29	29·64
(b) After leaching						
(i) Small aggregates						
Leachate	1·58	0·26	1·84	29·85	0·97	30·82
Soil	0·24	0·14	0·38	0·24	0·25	0·49
Leachate + soil	1·82	0·40	2·22	30·09	1·22	31·31
(ii) Large aggregates						
Leachate	1·45	0·20	1·65	30·78	0·74	31·52
Soil	0·24	0·14	0·38	0·28	0·17	0·45
Leachate + soil	1·69	0·34	2·03	31·06	0·91	31·97

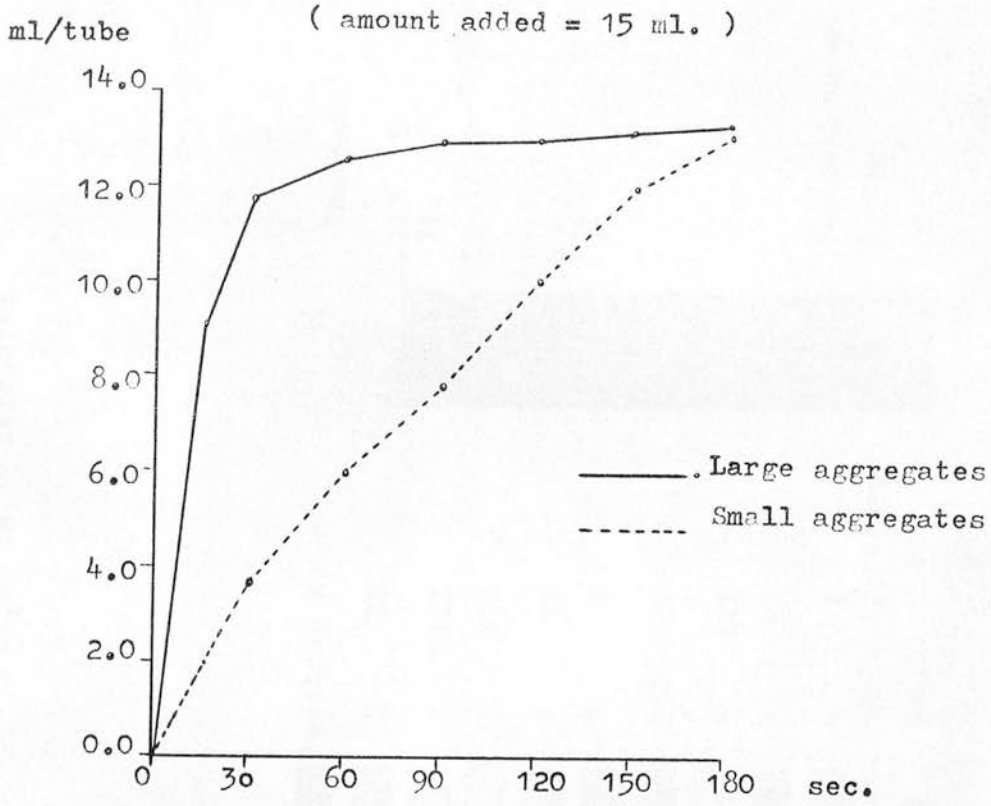
B: SAND

(Fig. 34b)

Leaching loss of NO_3-N from fine and coarse sand was very similar. Unlike the soil aggregates, about 95% of the applied NO_3-N was in the first leachate. The volume of the first leachate was far greater (average 8·9 ml.) from sand than (2·1 ml.) from soil aggregates.

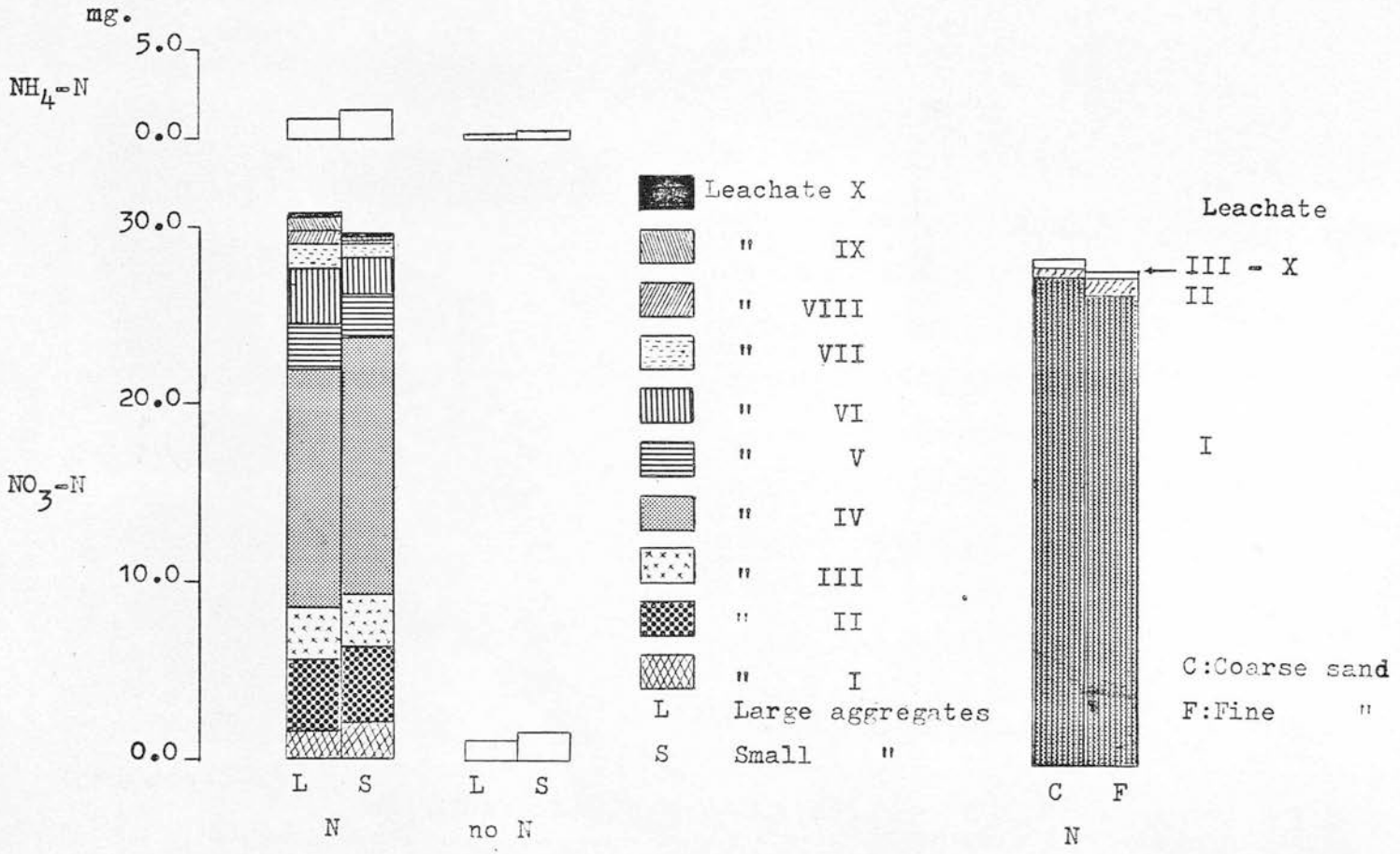
The amounts of NO_3-N leached from the sand during the experiment accounted for 97·6 and 95·5% (from coarse and fine sand respectively) of the applied fertiliser N.

Fig. 33 . Laboratory Experiment :
amount of water percolated from soil kept at W.H.C.
(amount added = 15 ml.)



Time following addition of water.

Fig. 34 . Laboratory Experiment :
leaching loss of NO_3- & NH_4-N in 10 leachates



(a) SOIL COLUMNS

(b) SAND COLUMNS *

* 1. no NH_4-N was detected.
2. no control was carried out

V DISCUSSION

FIRST:

FIELD EXPERIMENT 1969

Contents:

A: MINERAL N IN SOIL

[1] FALLOW

I: SEASONAL VARIATION:-

(a) Control treatment:-

The progressive NO_3-N increase in each horizon (Fig. 7) and profile (Figs. 13a & 18) between December and February was accompanied by a similar increase in NH_4-N (Figs. 8, 13a and 18) except between January and February when a decrease occurred in H_1 and H_2. These increases could result from an increase in mineralization due to one or both of the following mechanisms:-

1 - Increase in soil microflora:

There is already evidence (Eggleton, 1938; Rakhno, 1963; Stevenson and Chase, 1957) that a progressive increase in the population of soil microflora can occur during the winter. This increase may result in an increase in the mineralization of organic nitrogen.

2 - A fluctuation in soil temperature:

Between December and February, the soil temperature fluctuated just above the freezing point (Fig. 22), and this fluctuation in temperature may have increased the mineralization of organic nitrogen. Jager (1968) found that repeated freezing and thawing of soil increased the amount of mineral nitrogen; this was attributed to the partial destruction of the soil biomass by temperature changes, making it easier for micro-organisms to mineralize organic N. Reports of increases in mineral N resulting

from the freezing and thawing of soil are given by Harding and Ross (1964) and Chinman (1970).

During the winter and early spring, Campbell et al. (1970) obtained a pattern of NO_3-N similar to that found in this investigation viz. a progressive increase during the winter followed by a decrease in the spring. This was attributed to an upward movement of water, when conditions were relatively warmer. However, in this experiment, this factor is unlikely to have contributed much to the mineral N content of the surface horizons.

The pronounced decrease in the contents of NH_4-N in H_1 and H_2 between January and February (Fig. 8) resulted in a decrease in the profile content of NH_4-N at that time (Fig. 18b). However, although an increase in NO_3-N occurred in each horizon during this period (Fig. 7), this did not cause an increase in the mineral N (NO_3 + NH_4) content of H_1 and H_2 but the mineral N content of the complete profile was increased (Fig. 18c).

The decrease in NH_4-N in H_1 and H_2 between January and February could be due to:

1- Nitrification:

The increase in the NO_3-N content of the soil profile between January and February was associated with an equivalent decrease in NH_4-N (Fig. 13). Consequently there was little change in the (NO_3 + NH_4)-N between these two sampling dates. This suggests that nitrification of NH_4-N was largely responsible for the considerable decrease in this N fraction in H_1 and H_2 (Fig. 8) during this period.

2 - Loss during nitrification:

Gerretsen and De Hoope (1957) and Soulides and Clark (1958) reported a loss of N during the stage of nitrification between NH_4 and NO_3. They attributed this to a chemical reduction of the intermediate nitrite, NO_2. In addition, the nitrite ion might have combined with free NH_4 ion to form NH_4NO_2 which dissociates easily into N_2 and H_2O. Allison (1963) stated that the formation of NH_4NO_2 with its subsequent decomposition may be one of the major channels for N loss from soils of with pH values between 6.0 and 9.0

3 - Fixation:

The action of frost in the soil surface in February (Fig. 22) might have decreased the exchangeable NH_4-N content by increasing the capacity of the soil to fix NH_4-N (Walsh and Murdock, 1960).

4 - Volatilization:

The loss of NH_4-N through the formation and subsequent release of NH_3 may have been greater during the January to February period compared with December to January. Since the decrease occurred in the top soil (0 - 30 cm.) but not in the subsoil (30-60 cm.), some volatilization of NH_3 may have occurred. The NH_4-N in H_1, which increased from 20 ppm, at the commencement of the experiment, to 36 ppm in January may have brought about a parallel increase in NH_3 and subsequent loss particularly when the soil moisture content temporarily decreased and during freezing. Since the soil was not

acid (pH 7·0) the release of NH_3 is possible particularly when concentration of NH_4 ions reaches a fairly high level; such a level may have occurred during the period between January and February. Twenty per cent of the N, applied as NH_4-N at 50 ppm, which is not very much greater than the NH_4-N concentration found in this experiment, was lost by the volatilization of NH_3 (Volk, 1961). Markorov (1960) reported a loss of NH_3 equivalent to 20 Kg. N/ha during 10 days.

The loss of N as NH_3 has been reported by several workers (Wahhab, 1957; Overrein and Moe, 1967; Makorova and Ignotova, 1964; Hamissa and Shawarbi, 1962; Chao and Kroontje, 1964; Meyer, et al., 1961; DuPlessis and Kroontje, 1964).

In addition to these four channels which may have been responsible for the decrease, between January and February, in the contents of NH_4-N in H_1 and H_2, leaching of NH_4-N during that period could not be ruled out.

The decrease in NO_3-N + NH_4-N which took place between February and July occurred in each horizon and in the whole profile. This could be due to both immobilization and leaching of mineral N. The increase in NO_3- and NH_4-N contents of horizons between July and September suggests mineralization.

(b) Fertilized treatments:-

The seasonal variation in mineral N was different to that of the control (Figs. 7, 8, 9 and 13a). The difference was mainly

in the NO_3-N fraction and in 2 respects:-

1 - Horizons:

While the mineral N in H_2, H_3 and H_4 followed a similar pattern with time to the contents in corresponding horizons of the control, the mineral N content of H_1 of the fertilized plots decreased between December and May, increased between May and June then decreased in July.

2 - Profile:

While the NO_3-N of the control profile increased between December and February, then decreased till July, the content in the fertilized profiles increased slightly from December to February and then decreased between February and July.

In discussing the results, the two main periods (viz. Post-autumn from December to May, and post-spring from June to September) have been kept separate.

i: Post-autumn:

While the NO_3-N content of the fertilized H_1 did not vary appreciably between December and February, the content of H_2, H_3, and H_4 increased during this time. This must have some association with the application of fertilizer since: a) in the unfertilized plots H_1 as well as other horizons underwent an increase in their NO_3-N content during the same period (compare no N with N treatments, Fig. 7) and b) the pattern of change in the NH_4-N fraction was similar in both fertilized and control treatments (Fig. 8). These results suggest the following explanations with regard to the fertilized treatments:

1 - Leaching:

There was possibly more leaching of NO_3-N between December and February in the fertilized than in the unfertilized plots. At the December sampling (3 weeks after the application of fertilizer) H_1 contained more NO_3-N than H_2, but in January and February H_2 contained more NO_3-N than H_1 in a number of fertilized plots (Fig. 7). However there was never greater NO_3-N in H_2 than in H_1 in the control plots at any time during the season. The suggestion is that there has been a movement of fertilizer NO_3-N down the soil profile. Fertilizer NO_3 in the first instance is present mainly in the soil solution and is capable of moving rapidly down the profile in cracks and vertical channels created by earth-worms; and might have been leached to a greater extent than soil NO_3-N, due to differences in location within the soil particles. Nitrate originating from soil N is perhaps located and distributed more evenly within the solid phase of the soil, rendering it less easily leached than that of the fertilizer.

Shaw (1952) reported that fertilizer NO_3-N was leached from a heavy soil faster than from a light one. He attributed this to the structural cracks in the heavy soil, formed as a result of seasonal fluctuation of moisture content. Cunningham and Cooke (1958) reported results similar to those in this investigation when during the 2 months following the application of NO_3-N, a progressive increase in the NO_3-N content of soil surface (0 - 23 cm.) of the control plots occurred at the same time as a decrease occurred in

the fertilized plots. These investigators stated that the location of soil NO_3-N within the structural units rendered it less accessible to percolating water which passes around rather than in soil aggregates. Cooke (1967) stated the importance of soil aggregates in retaining soil NO_3-N against leaching.

In this experiment, the effect of soil structure in protecting soil NO_3-N against loss by leaching and at the same time encouraging the loss of fertilizer NO_3-N may have been responsible for the difference between fertilized and unfertilized treatments. This conclusion is supported by: (a) the good crumb structure of the surface soil and (b) the many vertical channels observed in the soil which were created by earthworms.

2 - Immobilization:

The introduction of fertilizer N might have caused more mineral N to be immobilized in plots receiving fertilizer than in the unfertilized (Andreeva and Shcheglova, 1968). There is some evidence (Peshakov, 1962; Steinbremer, 1963) of an increase in the population of micro-organisms, particularly those which immobilize mineral N, resulting from fertilizer N application.

3 - Denitrification:

Application of NO_3-N in the autumn might have encouraged some denitrification, at least temporarily, in localized anaerobic areas. The presence of some ploughed-in wheat stubble (which provides an energy substrate) could have contributed to denitrification under anaerobic conditions. Losses attributed to denitrification were reported in experiments carried out under conditions considered

practically aerobic (Jansson, 1958; Andreeva and Shcheglova, 1968; Stafanson and Greenland, 1970).

ii: Post-spring:

The surface horizons, H_1 and H_2 and the complete profiles of the fertilized plots had a greater NO_3-N content in June than in May. This was caused by the application of fertilizer NO_3-N in mid-May ($4\frac{1}{2}$ weeks before the June sampling); plots of unfertilized treatments underwent a decrease during the same May to June period. The surface of the soil was in a relatively dry condition at that time: it would readily absorb fertilizer NO_3- which would be carried to the inner pore spaces of the soil aggregates.

The decrease in NH_4-N in each horizon and profile between May and July is most likely due to immobilization and nitrification during that period.

II: CONTENTS OF MINERAL N IN FERTILIZED vs. UNFERTILIZED PLOTS:-

(a) Post-autumn period and fate of autumn applied N:-

A comparison of the contents of mineral N in fertilized and unfertilized horizons and profiles during December through May suggests that fertilizer N moved downwards through the soil profile. The processes of leaching, denitrification, and immobilization of fertilizer N may be discussed, in the light of these results, as

follows:-

1 - Leaching of fertilizer N:

The biggest difference in NO_3-N content between fertilized and unfertilized horizons (Fig. 7) and profiles (Fig. 13a) during the post-autumn period occurred in December, thereafter decreasing with time. Leaching is the most likely factor responsible for this difference being reduced with time. Even in December, between them, H_3 and H_4 of the fertilized plots had more (7 - 20 Kg. N/ha, i.e. 12 - 33% of fertilizer N) NO_3-N than their unfertilized counterparts (Fig. 7) which suggests that rainfall had already leached some fertilizer down the profile. However the total precipitation during the 3 weeks between the time of fertilizer application and the December sampling was 38 mm, not sufficient to remove all the fertilizer NO_3 from the profile. By May about 270 mm. of rain had fallen and this was high enough to leach practically all the fertilizer N remaining in a mineral form, beyond the 60 cm. profile. At this time the NO_3-N content in the fertilized profile was very much the same as in the unfertilized.

In an experiment on a similar (sandy loam) soil, Gasser (1962) showed that a winter rainfall of 203 mm. was sufficient to leach beyond the 60 cm. soil profile practically all autumn-applied fertilizer NO_3-N. Following that rainfall, horizons of fertilized and unfertilized plots were similar in their NO_3-N contents down to 60 cm.; below this depth (60 - 90 cm.) more NO_3-N occurred in fertilized over the unfertilized. Similar results were observed

in the data published by Nommik (1966a): 24 months after the application of fertilizer NO_3-N, far more mineral N was present in the 40 - 100 cm. of fertilized horizons than in their unfertilized counterparts while the surface 0 - 40 cm. horizons of each treatment had similar contents. Other workers (Olsen et al., 1970) studied the NO_3-N content in the soil down 300 cm. and found that, while little difference in NO_3-N content occurred between fertilized and control treatments in the top 60 cm., the difference was far greater at depths between 60 and 300 cm.

The results obtained in this experiment suggest that, by May, rainfall may have moved some fertilizer N beyond the 60 cm. profile.

2 - Immobilization of fertilizer N:

The immobilization of fertilizer N is suggested by 2 facts: a) Soon after application of fertilizer N (3 weeks after application, first sampling taken in December) there were far greater amounts of NH_4-N in fertilized than in unfertilized plots. This NH_4-N is probably an intermediary product during the process of immobilization of fertilizer nitrate N into microbial tissues. It is reported by Nasson (1962) and by Campbell and Lees (1967) that, in order to make use of the N in NO_3-N, micro-organisms have first to convert the latter into ammonium. This is likely to take place in the soil. Although the possibility of NH_4-N originating from fertilizer NO_3-N was ruled out by Broadbent and Stojanovic (1952), Jansson (1958) reported that during immobilization an appreciable part of fertilizer N (applied in form of NO_3) appeared in the ammonium form. Soil temperature during the winter (see Fig. 22) would not have prevented microbial activity entirely.

b) Three months after application of fertilizer nitrogen (February sampling), the amount of mineral N in H_1 was smaller in the fertilized than in the unfertilized plots (Fig. 9). Leaching could not be the sole reason for this decrease; an immobilization of nitrogen including fertilizer N may have occurred. The greater content of mineral N in May (mainly NH_4-N) in fertilized compared with unfertilized horizons (Figs. 8 & 9) and profiles (Fig. 13a) suggests a remineralization of that part of immobilized nitrogen.

Stojanovic and Broadbent (1956) showed that mineral NO_3-N added to soil could be immobilized at a rate of 28 ppm per day during the first 6 days. The immobilized N is mainly in forms which are fairly readily mineralized. Chang and Kurtz (1963) reported that 3 - 7% of the immobilized fertilizer N was in the insoluble humin fraction and about 90% in organic forms hydrolysable by acid or alkali. Chu and Knowles (1966) found that 13% of the immobilized fertilizer N was in the insoluble humin fraction and 50 - 60% in the amino acid fraction. Similar conclusions were made by Stewart et al. (1963). The amino acids are more easily decomposed by micro-organisms than other organic compounds (Bartholomew, 1963).

In this present investigation, a remineralization of this immobilized fertilizer N may have occurred between February and May. This type of remineralization has been reported by a number of workers (Broadbent, 1966; Overrein, 1967; Gasser et al., 1967). Overrein (1967) reported that immobilization and remineralization took place side-by-side and as early as the 3rd day after the application of fertilizer.

3-Denitrification:

The large quantity of NH_4-N produced in the fertilized plots (Fig. 8) also serves as an indication of the extent of denitrification; Woldendorp (1965) reported that denitrifiers can release NH_4-N from organic forms. A larger NH_4-N content of fertilized soil compared with the unfertilized occurred down to 60 cm. and until May when there was little difference in NO_3-N contents between the two treatments particularly in H_4. Some of the fertilizer NO_3-N which was leached down to H_3 and H_4 probably underwent denitrification.

The reduction of NO_3-N at depths (30 - 60 cm.) could have been by microbial and/or chemical means. The subsoil had approximately 4% organic matter (Table 1), which would supply denitrifiers with energy material and contained approximately 35 ppm NH_4-N; microflora can utilize NH4-N for their cell synthesis (Valera and Alexander, 1961). Furthermore, the occurrence in H_3 and H_4 of some heavy metals in the reduced state would increase the possibility of denitrification of NO_3-N (Wullstein and Gilmour, 1964; Wullstein, 1967; and Meek et al., 1970). Reducing conditions occurred in the subsoil in this investigation since mottled bands of gleyed materials were observed in the H_3 and H_4 (Platesl and 3). Although there were strong indications of leaching of fertilizer NO_3-N from the surface, at no time during the season did the subsoil (H_3 and H_4) of fertilized plots contain more NO_3-N than H_1 and H_2. This could be due to a rapid leaching and/or denitrification. Meek et al. (1969, 1970) reported a correlation between the redox potential and denitrification in a clay loam soil at different depths. There was a decrease in

redox potential with increase in depth. Meek et al. (1969) concluded that, although NO_3-N was leached down the soil profile, the rate of denitrification increased with depth consequently very little reached the drainage system. Lal and Tylor (1969) reported that denitrification in a silty loam was very active in zones immediately above the soil water table and that H_2 production was highest in the immediate vicinity of the water table.

Formation of NH_4-N as a result of application of fertilizer NO_3-N:-

The greater concentration of NH_4-N in fertilized horizons (Fig. 8) and profiles (Fig. 13a) compared with the unfertilized, particularly in December, is the result of the application of NO_3-N. This NH_4-N could have come from organic matter. An increase in the rate of ammonification, as a result of the application of fertilizer NO_3-N, was reported by Broadbent and Stojanovic (1952) but there was little evidence that this NH_4-N originated from the fertilizer. Woldendorp (1965) reported similar results: only 1% of the NH_4-N formed under anaerobic conditions coming from added NO_3-N, the remainder having been ammonified by denitrifiers from organic compounds in the soil. Broadbent (1965) postulated that the osmotic effect of the fertilizer caused the microbial cells to break and release nitrogenous protoplasm to ammonifying processes. This would be particularly effective in regions immediately surrounding granular fertilizer soon after application. An increase in the population of ammonifying organisms upon application of mineral fertilizers was reported by Voinova-Raikova (1963). The

production of NH_4-N as a result of the application of fertilizer N was also reported by Bremner and Shaw (1958) and Andreeva and Shcheglova (1966,1967,1968).

In view of these findings, it seems probable that, in this experiment, the extra NH_4-N formed in the fertilized plots originated mainly from the soil organic N. However, there is a possibility that some NH_4-N originated from NO_3-N as an intermediate product in the immobilization as has been reported by Jannson (1958).

(b) Post-spring period and fate of fertilizer N:-

There was a movement of fertilizer NO_3-N in the soil profile; this was indicated by the larger NO_3-N contents in fertilized plots in each of the 4 horizons as compared with the unfertilized ones. During the post-spring period, movement of fertilizer N seems to be slower as compared with the post-autumn period. This is suggested by the following.

1 - Fertilized H_1 horizons maintained a superiority over their unfertilized counterparts throughout the post-spring period and for 17 weeks whereas such superiority ceased on the 12th week following autumn application.

2 - The biggest difference in NO_3-N between fertilized and unfertilized H_3 and H_4 did not occur till September, i.e. 17 weeks after the spring application, but in the post-autumn period the biggest difference occurred only 3 weeks after autumn application. The drier conditions during the summer (Fig. 21c) would slow down the movement of NO_3-N.

3 - At no time during the post-spring period did the underlying H_2 contain larger amounts of NO_3-N than H_1; during the post-autumn period this occurred in January and February.

Some immobilization of fertilizer NO_3-N may have occurred during the spring and summer. In June the difference in NO_3-N between fertilized and unfertilized profiles (Fig. 13a), on average, accounted for 48% of the amount of fertilizer N applied in the spring. As movement of fertilizer NO_3-N seemed to have been slow, the 52% deficit is less likely to have been caused by leaching alone, immobilization may have contributed to this loss. Conditions conducive to denitrification are less likely during the spring and summer.

[2] PLANTED

I: SEASONAL VARIATION:-

(a) Control treatment:-

The seasonal variation of NO_3- and NH_4-N in the planted control soil was similar to that in the fallow as there was more mineral N in the soil during autumn and winter than during the spring and summer.

The uptake of N increased during the spring and summer (Fig. 19) and this was the main reason for the decrease in the mineral N content during this time compared with the autumn and winter.

As in the fallow soil, there was a decrease in the NH_4-N content of H_1 and H_2 from January to February. The explanations

given for the similar decrease in fallow treatments (page 144) are also appropriate here.

(b) Fertilized treatments:-

The decrease in NO_3-N in H_1 from December onwards (Fig. 10) suggests the following:

1 - Leaching:

Most of the applied fertilizer N was present in H_1 at the December sampling but this was gradually leached during the winter. Three facts (Fig. 10) support this theory: (a) H_2 had greater NO_3-N contents than H_1 in February and this did not occur to unfertilized plots; (b) There was a build-up of NO_3-N in the subsoil H_2, H_3 and H_4 which continued between December and February; and (c) There was a smaller difference in NO_3-N contents between different horizons in fertilized compared with the much wider difference in the case of unfertilized in February.

2 - Immobilization:

Immobilization would take place in planted soil in the same way as in the fallow. The microbial population would increase in the presence of living plant roots (Bartholomew and Clark, 1950; Katznelson and Bose, 1959); and results in an immobilization of mineral N by microflora

3 - N uptake by plant:

Plants grown in planted plots removed some N from the soil (Fig. 19). This uptake ranged from 2 Kg. N/ha during the winter months of December to February to about 12 Kg. N/ha during May and

continued to increase from then onwards: by September the amounts of N removed from the soil by plant (above-the-ground parts) were as high as 37 to 152 Kg. N/ha. This progressive increase in N removal from soil by means of the plant has, most certainly affected the contents of mineral N in planted soil, particularly the surface 15 cm. (H_1) where the majority of plantsroots are present (Russell and Ellis, 1968), see Plate 10.

II: CONTENTS OF MINERAL N IN FERTILIZED vs. UNFERTILIZED PLOTS:-

The fertilized plots contained far more mineral N than the unfertilized during December and January (Fig. 12) when plant growth was negligible and had little effect on the mineral N status of the soil. Also the difference in mineral N content between fertilized and unfertilized soils is almost entirely NO_3-N, and this accounts for about 60% of the amount applied.

(a) Post-autumn period and fate of autumn applied N:-

In the light of these results, the processes which may have occurred to fertilizer N are discussed as follows:

1 - Leaching of fertilizer N:

In January H_3 and H_4 had more NO_3-N in the fertilized compared with the unfertilized plots. This did not occur in December. The downward movement of fertilizer N was therefore not very rapid.

2 - Immobilization of fertilizer N:

Immobilization of fertilizer nitrogen is suggested by the

smaller content of mineral N in the top-soil of fertilized plots (0 - 30 cm.) in February than in the unfertilized ones (Fig. 12): immobilization was, most likely, taking place throughout the preceding period; but as there was, then, an abundance of fertilizer nitrogen not yet leached from these H_1 and H_2 horizons, fertilized plots showed more mineral N than the unfertilized ones. The microbial population decreases rapidly with increase in depth of soil (Eno and Ford, 1958). Therefore the more biologically active top-soil is likely to have more immobilization.

3 - Denitrification:

The possibility of denitrification of NO_3-N cannot be ruled out. Woldendorp (1963) reported that more NO_3-N was lost through denitrification in the presence of living plant roots than in their absence; the reason was attributed to root excretion of organic material providing energy for denitrifiers.

4 - N uptake:

The uptakes of N from fertilized and unfertilized plots were similar during the post-autumn period. However, uptake and subsequent exudation of N, some originating from fertilizer N, may have taken place during the winter. Bowen (1969) found that the roots of plants receiving fertilizer N excreted 10 times as much N in organic forms (amido and amino acids) as those which had not received any. Boatwright and Haas (1961) and Gasser and Iordanou (1967) stated that an excretion of N by wheat may occur during the growing season. Woldendorp et al. (1965) reported that within a period

of 3 weeks a considerable proportion of N taken up by perennial ryegrass grown in pots was translocated from leaves to roots from which it seemed to have been excreted to the soil.

(b) Post-spring period and fate of fertilizer N:-

The similarity in NO_3-N contents of the control and fertilized treatments is due to a greater uptake of N by plants from the latter.

[3] SOIL PLANT SYSTEM AND MINERAL N IN SOIL (Fallow vs. Planted)

In comparing mineral N content in planted soil to that in the unplanted, there seem to be two mechanisms affecting the status of mineral N in soil. These two mechanisms are: (1) retention of mineral N against leaching through means other than uptake, and (2) uptake of N.

I: THE ABILITY OF PLANT ROOTS TO RETAIN NO_3-N AGAINST LEACHING:-

Two examples of this occur in December (Fig. 14) when the difference between planted fertilized and unfertilized soil was greater than at any other time during the post-autumn period.

(a) In the unfertilized treatment (Fig. 14), each of the planted horizons contained more NO_3-N than the fallow. The mineral N was, thus preserved to a greater extent by the presence of living plant roots.

(b) The fertilized planted treatment (top 30 cm. - H_1 and H_2)

contained more NO_3-N than the fertilized fallow. While A_1 and A_2 produced similar NO_3-N contents in these two horizons in the fallow plots, A_2 contained more than A_1 in planted plots. The speed of leaching of fertilizer N down the profile was slower in planted profiles than in fallow. In addition there was more NO_3-N in the subsoil (H_3 and H_4) of fallow plots than in the planted.

There are two ways in which plant roots could have retarded the downward movement of fertilizer nitrogen:

(a) Adsorption of ions on root surfaces:-

Williams (1962), Bartlette (1964); While et al. (1965); Franklin (1966) reported that plant roots have the ability to adsorb ions on their surface. Thus an adsorption of cations on the cation exchange sites on roots is certain to have occurred in this investigation: perhaps some NO_3^- anions were attached to these adsorbed cations. On the other hand, the NO_3 ion itself can be adsorbed on the anion exchange sites of roots. In both cases, viz. adsorption of cations or anions, the presence of roots in the soil is bound to increase its retention of fertilizer N. While et al. (1965), Blanc (1967), and Bartlette (1964) reported that after applying fertilizer N, both cation and anion exchange capacity of plant roots increased.

(b) Soil-water relationships:-

Data published by Bavel et al. (1968) showed that during the growing season (a) the downward movement of water through the soil profile was quicker in fallow than in planted plots and (b) that evapo-transpiration was higher from the planted than from fallow soils. The plant cover

in this experiment would reduce the rate of downward movement of water and therefore the rate of movement of fertilizer NO_3-N, resulting in a higher NO_3-N content in planted than in fallow profiles.

A further indication of the effect of the plant in slowing down the downward movement of fertilizer NO_3 is given at the January sampling when for the first time since autumn application, H_4 horizons of planted fertilized plots contained more NO_3-N than their unfertilized counterpart (Fig.10). In comparison to this situation (Fig. 7), in the fallow fertilized H_4 horizons, it was early in the season, in December, when they first showed a greater NO_3-N than their unfertilized counterparts. This shows that when no plants were grown, fertilizer NO_3-N moved faster down the profile than when plants were grown.

II: REMOVAL OF MINERAL N FROM SOIL BY PLANT (UPTAKE):-

During the period of active plant growth (May to September) the much smaller contents of mineral N in planted horizons (Fig. 16) and profiles (Fig. 17) compared with fallow is mainly caused by the removal of N by plant (uptake).

B: N UPTAKE BY PLANTS

(Table 6; Fig.19)

Less than 3 Kg. N/ha were removed by the aerial parts of the plant during the winter (from November to February) on each of the N treatments (no N and N). During that time there was too little growth (Plate 11) for any sizeable effect on the uptake of nitrogen.

With the re-commencement of growth in the spring there was an increase in the uptake of N by the plant. However even in May, N uptake from fertilized plots was not much greater than that from the control. At this time, an additional (i.e. over the control) 1 Kg. N/ha only was taken up by the plant tops in plots receiving 30 Kg. N/ha; and not more than 4 Kg. N/ha where 60 Kg. N/ha was applied. Despite the fact that, by May, most of autumn-applied fertilizer N was not present (as NH_4-N or NO_3-N removed by leaching or by transformation into other non-mineral forms) the increase in N uptake between May and June was much greater in the N-treated plots than in the no-N ones. While the plants in the control plots took up 16 Kg. N/ha during May to June, those in the fertilized plots took up an average of 71 Kg. N/ha during the same period. Besides, the uptake in the A_2 plots was 25 Kg. N/ha more than in the A_1; the equivalent difference between the two spring-application treatments (S_1 and S_2) was far less (6 Kg. N/ha). This shows that despite an interval of 4 weeks between the spring application of N and the June sampling, the increase in N uptake which occurred was the result of the autumn applied fertilizer rather than that applied in the spring.

One or more of the following factors could have been responsible for the positive relationship between the increase in uptake and rate of autumn applied N:

1 - Increase in root volume:-

During the winter and early spring, i.e. following the autumn application, there would be a small increase in the volume of root corresponding to an increase in the rate of autumn applied fertilizer, and as a result when the large demand for N occurred in June the bigger root system on the A_2 plots would be able to remove a greater amount of nitrogen than those which had received the smaller dressing of fertilizer in the autumn. Srivastava (1970) reported that by increasing the volume of roots, there was an increase in N uptake.

In this experiment, the roots may have been able to recover some fertilizer nitrogen which had moved beyond the 60 cm. profile. Development of roots during the winter is stated to occur by Leonard and Marten (1963); and may reach as deep as 90 cm. Nommik (1966a) questioned the depth at which fertilizer is considered lost. In his study of mineral N content of fertilized horizon down to 100 cm. deep, he concluded that wheat roots seem to recover nutrients leached down to this depth.

2 - Remineralization:

Autumn applied N which had been immobilized was perhaps remineralized during the latter part of the post-autumn period (i.e. February to May), and subsequently taken up by plants. This coincides with the results for mineral N in the planted soil

(Figs. 10 and 11) which suggested some remineralization of fertilizer N: in May the fertilized profiles of both fallow and planted soils (Fig. 13) regained their superiority in mineral N over their unfertilized counterparts; in February there had been less mineral N in fertilized than in unfertilized plots.

3 - Translocation from roots to tops in June, of fertilizer nitrogen which had been stored in roots during December to May:

Lapin and Watson (1970) reported that an appreciable amount of N was translocated from roots to the stems and leaves of a monocotyledon (Brome grass) at a late stage of its growth (flowering stage). They found that total N uptake by roots reached its highest two weeks following sowing, thereafter there was a decrease. Plant tops on the other hand continued to increase up to the 8th week.

In this investigation, there may have been an 'extra' or 'luxury' uptake of N by roots in fertilized plots during the cold post-autumn period. With little vegetative growth, this extra N is stored in the roots until vigorous growth of the vegetative part is resumed. Thus in spring and summer there would be a translocation of this extra N from roots to tops.

Power et al. (1970), growing barley in growth chambers, found that a temperature of $9^{\circ}C$ did not prevent roots from removing N from the soil. These investigators found that during the first two months of growth, there seemed to be a restriction in translocation of N from roots to tops; but thereafter a rapid translocation of N to tops occurred.

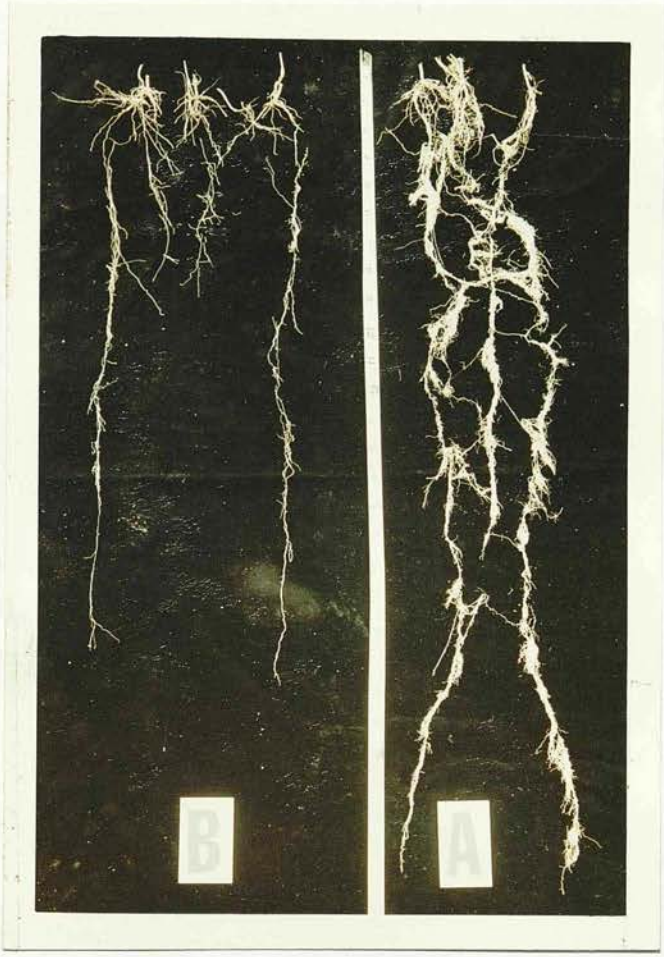
Furthermore, the NH_4^+ and NO_3^- ions adsorbed on the root hairs, and not taken up by the plant during December to May, would be taken up when growth was more active.

It took more than 4 weeks for the spring-applied nitrate N to clearly manifest itself in the uptake by the plant: in June the uptake difference between S_1 and S_2 treatment was 6 Kg. N/ha. In September it was 26 Kg. N/ha which approached the 30 Kg. N/ha difference between the two rates of application. This would suggest a delay in translocation, of spring applied N taken up by roots, from roots to tops.

At the end of the season, plants which had received A_2 removed more N than those of A_1; this is in agreement with reports by Srivastava (1970) who stated that application of fertilizer to crops at an early stage of growth, well before the peak uptake, though apparently wasteful, will provide sufficient available nitrogen for a late stage of growth.

Plate 10: Field Experiment.

Effect of fertilizer on root extension.



A: Fertilized: A_2S_2 (60 Kg. N/ha in December.
90 Kg. N/ha in May)

B: Control: no fertilizer N applied.

Plate 11: Field Experiment

Growth of winter wheat during the season.

(for experiment layout see Fig. 1)

a: January.

Plate 11 b: June

Plate 11 c: August.

GENERAL DISCUSSION ON THE FIELD EXPERIMENT

Sampling, Design and statistics

Under the conditions of this experiment, there was a considerable soil variation within replicates of the same treatment. These variations are associated with the nature of the soil which showed some degree of heterogeneity. The results showed that in order to minimize the effect of soil heterogeneity, the effort should be stressed on increasing the number of plots (replicates) per treatment rather than the number of samples taken per plot. Because of this heterogeneity, there were few statistically significant effects, particularly during the winter and spring.

Hence as a result, the general pattern of change in contents of mineral N in soil horizons and profile, along with N uptake, throughout the season provided the basis for the study of the fate of applied fertiliser N to the soil.

Fate of nitrogen

The top 30 cm. soil surface seems to be of a considerably high biological activity with a large reservoir of organic N which provided a source for high amounts of mineralizable nitrogen. Although the temperature of the soil during the winter and early spring was far from warm (see Fig. 22), an increase in the contents of mineral N occurred in soils of both fallow and planted systems. Beside this 'winter-increase', the contents of mineral N in the winter as compared with the summer was higher. It was thought most likely that, as a function of soil moisture, which was greater in winter than in summer,

there may have been a greater number of microflora during the former than the latter season: with more microflora, more ammonification occurred. Also, fluctuation of soil temperature below and above zero may have encouraged decomposition of soil organic matter during the winter.

There was a rather high (100 - 170 Kg./ha of soil profile) content of ammoniacal N in the soil, particularly in the top 30 cm. and this was subject to nitrification as well as - seemingly - fixation exerted by temporary freezing of soil during the winter.

The marked increase, as well as the considerably high content of mineral N - apparently originating from the soil N fraction - caused some obscurity on the changes occurring to fertilizer N. However, leaching of fertilizer N seemed to have been the most important channel through which fertilizer N goes. After a short lapse of 3 weeks time following fertilizer application in autumn, soil in as deep a location as 60 cm. from the surface showed higher contents of NO_3-N (amounting to 10 - 20% of the applied N) in fertilized over unfertilized soil. The retention of fertilizer N by the 60 cm. soil profile against loss by leaching did not last more than 3 months and in February contents of fertilized and unfertilized plots were not very much different.

Immobilization and denitrification in addition to leaching seemed to have taken place. The first mechanism was manifested in two phenomena a) a marked decrease in mineral N contents in fertilized as compared with unfertilized soil in Feb. and b) an increase in May (perhaps due to remineralization).

The second mechanism was suggested by the following phenomena a) the increase in moisture content, and b) the presence of large quantities of NH_4-N at depth (30 - 60 cm.) in February in particular despite the apparent marked downward movement of fertilizer NO_3-N. It seems that although causing more complications - addition of fertilizer N enhanced mineralization.

The effect of the plant was marked, during the winter, although the N uptake and growth was too small to exert any significant influence. It seems that the development of roots, which may have reached a large degree after sowing, contributed to the conserving effect of the plant against loss by leaching of fertilizer N. A possible exudation of some N from the plant to the soil might be suggested as an explanation to the similarity of N uptake by fertilized and unfertilized plants during December to February.

Dry weather during the summer secured a greater degree of retention of fertilizer N against loss by leaching, but there was no deterrent against immobilization. Active plant growth during this period, along with the considerable rate of removal of N from the soil, helped in securing a large part of fertilizer N against losses by either channel: in September from 67 to 77% of fertilizer applied to planted soil throughout the season was recovered by the above-ground parts of plant. Denitrification during the summer seems unlikely and no indication of its occurrence was encountered in the experiment, although Greenwood (1963) showed that denitrification could occur when rain followed a period of drought.

The conserving effect of the plant on fertilizer N against losses from the mineral pool - within the soil profile - seems to be due to (a) actual uptake by plants (b) provision of an extra surface (root surface) for mineral N ions to adhere to and (c) increasing upward movement of water in the soil by means of transpiration.

SECOND: GREENHOUSE EXPERIMENT I:

"Losses of fertilizer nitrogen from soil columns"

Contents:

- Mineral N in soil
- Immobilization of fertilizer N
- Denitrification of fertilizer N
- N uptake at different stages of plant growth
- Leaching losses.

MINERAL N IN SOIL HORIZONS (Fig. 24):-

The pattern of mineral N contents in the soil horizons suggests a fairly rapid downward movement of mineral N through the soil columns in solution in the irrigation water. The increase in mineral N with depth occurred under each of the three water regimes. During the 7 weeks of the experiment the water applied was equivalent to 93, 136, and 1025 mm. rainfall for R_1, R_2 and R_3 respectively. Bates and Tisdale (1957) applied water to columns of a sandy soil at levels equivalent to 7, 20, 33, 46, and 59 mm. rainfall, none of which was sufficient to allow leaching. At each level there was a downward movement of NO_3-N; the extent of which was closely related to the amount of water applied. In a field experiment Wetselaar (1962) reported similar results in a clay loam soil profile 150 cm. deep with a rainfall greater than 380 mm. In a leaching experiment Webster and Gasser (1959) applied 40 mm. of water to a 12 cm. sandy clay loam soil column and found that fertilizer NO_3-N was washed completely from the soil column.

In this experiment the presence of fertilizer N in the soil column was illustrated by the larger contents of mineral N in each of the fertilized horizons compared with their unfertilized counterparts (Fig. 24a). The amount of mineral N in the H_3 horizon was greater in R_1 and R_2 treatments where no leaching occurred than in R_3 where watering was sufficient for leaching to take place (Fig. 24b). A considerable loss of mineral N must have occurred in the drainage water with R_3. This is shown by (a) the similar quantities of

mineral N in the three horizons of the R_3 treatment and (b) the mineral N content of each of the R_3 horizons was about half that in the corresponding R_1 or R_2 horizons.

These results show that by confining the amount of water added to soil within the range of water holding capacity, fertilizer N was not lost by leaching; but nevertheless there was a decrease in the mineral N content of each horizon as a result of increasing the water regime from 60 to 90% of water holding capacity (from R_1 to R_2). Processes other than loss by leaching must have been responsible, perhaps denitrification and immobilization. The effect of the plant in removing mineral N from soil horizons is reflected in the smaller mineral N content of planted than fallow horizons (Fig. 24c).

The decrease in mineral N with time (Fig. 24d) is perhaps due to immobilization and denitrification, N uptake, and leaching losses all of which increased with time.

MINERAL N IN SOIL COLUMNS (Fig. 25a).

Apart from N uptake and leaching, the main processes suggested by results for the contents and change with time of mineral N in soil columns are immobilization and denitrification.

Immobilization of fertilizer N:

The R_1 topsoil treatment (Fig. 25a - R_1) gives a clear picture of the extent of the immobilization of fertilizer N. With this particular treatment there was (i) an absence of competition between uptake and leaching; (ii) the moisture content was relatively small (60% of W.H.C.) and denitrification should be at minimum compared with other watering regimes; (iii) a larger microbial population in the topsoil capable of immobilizing N to a greater extent than the subsoil.

The activity of the microorganisms - the main agents of biological turn-over - in the fallow R_1 topsoil treatment is shown by the unfertilized columns when a big increase (more than two fold) in the mineral N content took place between the 3rd and 7th week. No change occurred during the same period in the equivalent subsoil treatment. Ekpete and Cornfield (1966) reported a peak of mineralization at mosture contents of 50 - 60% W.H.C.

The first signs of immobilization of fertilizer N were in the slight decrease in mineral N contents of the fertilized treatments between the 3rd and 5th weeks. During this period, mineral N decreased by 7 Kg. N/ha in the fertilized columns, at the same time an increase of 24 Kg. N/ha occurred in the control treatment. It seems likely that when fertilizer N was applied there was either an

increase in immobilization or a suppression of mineralization. Broadbent (1966) concluded that application of mineral N to soil alters the equilibrium which exists between organic and inorganic N in the soil and causes a rapid interchange between the two forms. This worker found that within 3 - 5 weeks of applying fertilizer N, 20 to 30 percent had appeared in the organic fraction of the soil. Vlehlova (1963) reported that fertilizer NO_3-N depressed nitrification. A similar effect may have occurred in this experiment.

A rapid increase in the rate of immobilization of fertilizer N was reported by Stojanovic and Broadbent (1956) who found that 2-6 days after applying 88 kgN/ha, 60kg. N/ha per day (of total mineral N in soil) were being immobilized. Jansson (1958) reported that within 5 weeks 14 percent of fertilizer N was immobilized, at the same time, soil organic N was undergoing mineralization at a rate similar to that in unfertilized soil.

From the 5th week onwards, the results for the fertilized fallow R_1 topsoil show that mineral N was being released. However there was only 8 Kg. N/ha more mineral N in fertilized columns over the unfertilized ones (a proportion of 12 percent fertilizer N) by the end of experiment. This shows that immobilization of fertilizer N was taking place along with mineralization of soil organic N.

The subsoil showed a smaller extent of immobilization and this was demonstrated by the constant difference in mineral N content between the N and no N R_1 fallow columns during the first to last sampling (i.e. 3rd to 7th week). However, in this particular soil treatment, the apparent recovery of fertilizer N was less than the

amount applied; an average of about 50 percent was recovered. There may have been mechanisms other than immobilization responsible for this small recovery. A chemical reduction of NO_3-N into volatile nitrogenous compounds or N_2 may have occurred under the effect of some highly reduced compounds (e.g. Fe^{++}, Mn^{++}) in the subsoil.

The possibility of immobilization in the fallow R_2 treatment in both topsoil and subsoil could not be ruled out although at this 90% W.H.C. moisture content denitrification is likely to have taken place. The increase (19 Kg. N/ha) in mineral N content of the fallow fertilized R_2 topsoil (Fig. 25a) between the 5th and 7th week may have been due to mineralization of previously immobilized N.

Immobilization of fertilizer N in planted treatments may also have taken place. At the end of the experiment the recovery of fertilizer N by plant from the R_1 and R_2 topsoil was 53 and 67 percent respectively; but in the soil itself there was none or little difference in contents of mineral N between fertilized and unfertilized columns. This may have been caused - partly at least - by immobilization. Paul and Myers (1971) reported recoveries of 59 and 71 percent of fertilizer N by plant, while immobilization was taking place concurrently; from 12 to 25% of fertilizer N was immobilized within 12 weeks.

Denitrification of fertilizer N

A loss by denitrification may have taken place in the R_2 treatments in particular where moisture content was kept fairly high. Corey et al., in a laboratory investigation (1967) reported that denitrifiers reduce NO_3-N in soil solution when oxygen concentration becomes critical. At a flow velocity of water of 0·11 cm./hr. there was 20 percent loss by denitrification. Increasing the flow velocity of the NO_3 solution to 1·32 cm./hr. did not allow any denitrification and applied NO_3 was recovered in the leachate.

Maintaining the soil at 90 percent water holding capacity is most likely to cause denitrification particularly with a supply of organic matter as a source of energy. The pattern of change in mineral N of the fallow R_2 topsoil suggests a denitrification of fertilizer N. The decrease of 68 Kg. N/ha in fertilized soil between the 3rd and 5th week could be largely caused by denitrification.

Olsen et al. (1970) reported the formation of NO_2 after 4 weeks of incubating a light soil at 90% W.H.C. Stefanson and Greenland (1970) found that half the applied fertilizer N volatilized as N_2 and volatile N oxides during 5 weeks at 100% W.H.C. The importance of a static condition of water was elucidated by Corey et al. (1967) who stated that while 50% of applied NO_3-N was denitrified under waterlogged conditions, only 20% were lost when waterlogged but maintaining a 0·11 cm./hr. flow of water. It seems that elimination of dissolved oxygen was the main reason for this.

While immobilization and denitrification seem to account for the loss of the main part of fertilizer N in R_1 and R_2 fallow soil respectively, with R_3 by permitting leaching of the major proportion of fertilizer N, only 12% of it seems to have been denitrified and/or immobilized.

N UPTAKE (Fig. 25b)

Uptake of N by the plant continued throughout the experiment. There was a greater uptake of N from topsoil than from subsoil as a result of applying fertilizer N. This is due to better plant growth in the topsoil perhaps because of chemical and physical reasons. The following are contents of P, K, organic matter, and the texture of each of the 2 soils:

	P (ppm)	K (ppm)	organic matter (%)	texture
Topsoil	16	233	5·7	Loam
Subsoil	4	117	4·4	Sandy loam

The smaller organic matter content of the subsoil compared with the topsoil may have caused the subsoil aggregates to collapse with frequent watering causing a reduction in the pore space. The unfavourable conditions in the subsoil were not offset by the application of fertilizer N, therefore there was a small response to the application of nitrogen. In the subsoil the uptake of N by fertilized plant was only slightly greater than that by the unfertilized.

N uptake will be discussed for each of the three samplings:-

First: N uptake during the first 3 weeks:

Most (from 50 - 80%) of the uptake occurred during the first 3 weeks of the experiment. This is in agreement with results published by Wilman (1965) who found that from 65 to 70% of the total N uptake over 6 weeks occurred during the first 3 weeks of an experiment. The yields of dry matter (Fig. 23) suggest that most of the growth occurred during the first 3 weeks when the greater part of N uptake took place. The rate of uptake of fertilizer N was also greatest during the first 3 weeks. Bartholomew and Hiltbold (1952) reported that recovery of fertilizer N by oats did not change between the 5th week and the end of the 10-weeks experiment. In the present investigation there was no increase in the recovery of fertilizer N after the 3rd week, which suggests that the plants quickly removed most of the fertilizer N during the first 3 weeks. Martin et al. (1963) reported that Rhodes grass removed most of fertilizer N in the first 6 weeks of growth leaving negligible amounts of it in the soil to be subject to immobilization or denitrification.

In the topsoil, where the plants apparently removed 73, 65, and 52% of fertilizer N from R_1, R_2, and R_3 respectively, the decrease in this recovery with increase in watering is probably due to the following:

1. Increase in denitrification

The possibility of a greater degree of denitrification is expected as a result of increasing the water content from 60 to 90 to 100% of W.H.C. (i.e. R_1, R_2, and R_3 with allowance of leaching

of water in excess to W.H.C.). Aeration and the drying of soil between waterings - particularly in the top horizon, was apparently greater in R_1 than R_2 or R_3. The possible permanent wet condition of H_2 and H_3 horizons of R_2 and R_3 in particular is most likely to have caused more denitrification.

2. Leaching losses:

The loss of mineral N by leaching (R_3) removed it beyond the reach of plant roots. About 30 percent of the fertilizer N was lost by leaching during the first 3 weeks. This could explain the lower recovery of fertilizer N with this treatment.

Second: N Uptake during the 3rd to 5th week:

The decrease in the rate of uptake of 'apparent' fertilizer N during the first 3 weeks is in fact caused by an increase in the rate of uptake in the control columns during the later period. The increase in N uptake between the 3rd and 5th weeks was twice as much in control plants as in their fertilized counterparts. This may have been due to the release to the soil of some of the N in plant tissues. The contents of fertilizer N in the soil of planted topsoil R_1 columns (Fig. 25a) may give evidence supporting this theory: In this treatment (no leaching) where much denitrification is unlikely, the quantity of fertilizer N remaining in the soil was doubled between the 3rd and 5th weeks. The possible translocation of N from the plant to the soil was suggested by Boatwright and Haas (1961) studying N uptake by wheat. Lapins and Watson (1970) reported that after 6 weeks the rate of N uptake by Brome grass decreased and this was attributed to a movement

of N from plant to soil. Huntjens (1971) also reported excretion by plant of some of the uptaken fertilizer N.

Third: N uptake during the 5th to 7th week:

The increase in uptake between the 5th and 7th weeks was greater with fertilizer than without in treatments R_1 and R_2, suggesting that there was still more fertilizer N remaining in the soil at the 5th week. With the R_3 treatment, on the other hand, the decline in yield (Fig. 23) during this period corresponds with a decrease in N uptake. Growing roots may have reached depths where moisture was increasing and was retarded because of waterlogging. A sloughing off of part of the plant tissues caused a transfer to the soil of N which was previously in the plant. Huntjens (1971) reported that 25% of the N in roots could be transferred to the soil in this way.

LEACHING LOSSES (Fig. 25c):

The leaching removed three quarters of the fertilizer N from the topsoil and almost all from the subsoil where the soil was left fallow. The lack of plant cover is a major cause of the substantial loss. Two other factors have contributed to this loss:

1. High precipitation (watering).

The amount of water applied to R_3 treatment during the first 3 weeks was 482 mm., and 1025 during 7 weeks. Wetselaar (1962) stated that precipitation is the most important factor affecting movement of fertilizer N in the soil. In a clay loam he found that the movement of fertilizer NO_3-N down the soil profile was about 1 mm. per mm. of precipitation. Bates and Tisdale (1957) reported a greater movement in a lighter (sandy) soil. In this experiment, a precipitation of more than 482 mm. would move fertilizer N completely from the soil column (length = 450 mm.) on the basis of the above results.

Paauw (1962) reported that half the contents of soil mineral N was lost from a 50 cm. profile when rainfall increased from 164 to 205 mm. Paauw (1968) reported a similar proportion lost as a result of increasing the rainfall from 204 to 537 mm. Owens (1960) demonstrated the effect of increased precipitation on the loss of mineral N: rainfalls of 300, 450, 600 mm. caused a loss of N by leaching of 9, 40, and 43 Kg. N/ha respectively from a 95 cm. deep lysimeter.

2. Soil texture.

Neither the topsoil nor subsoil were heavy textured soils (loam and sandy loam respectively). In addition they were mixed with coarse sand in the ratio 1:1 by weight for the purpose of the experiment. This made them even lighter. With excessive watering permitting leaching such soils are expected to lose in the drainage a considerable proportion of applied fertilizer NO_3-N.

Effect of the plant on leaching of fertilizer N:

The effect of the plant on the loss of mineral N - in general - by leaching is shown in two observations:

(a) The smaller leaching losses (less than half) from planted than from fallow topsoil, fertilized or unfertilized.

(b) The smaller amount of 'fertilizer N' leached from the topsoil than from the subsoil where there was less growth.

Karraker et al., (1950) showed that from 15 to 58% of fertilizer N were lost by leaching from planted soil whereas 74% were lost from fallow. Similar results were reported by Ayres and Hagihara (1963) and by Law and Armitage (1970). Overrein (1969) reported that a 140 mm. precipitation on a profile (40 cm. deep) with a sandy soil without crop, removed nearly all the fertilizer N in 4 weeks.

Although plants retained a considerable proportion of fertilizer N within the soil-plant system, this noticeable effect lasted for the first 5 weeks only. Between the 5th and 7th week, over 80 percent of the fertilizer N had been lost by leaching. One or more

of the following may have caused this:

1. The decline in plant growth.

There was a retardation of plant growth of R_3 following the 5th week (see plate 12, Fig. 23) and death of part of the plant leaves. The dead parts of plants must have released N to the soil. This released N may have been mineralized from organic forms by soil microflora; or some of this released in a soluble form.

2. Removal of N from plant to soil.

Excessive watering may have caused some of the soluble nutrients to be washed from the plant tissues into the soil. There is ample evidence of nutrients being removed from living plant tissues under the effect of rain. Zazvorka (1959) reported that barley plants lost 22 percent of their K after 8 hours of rain: Tukey and Mecklenburg (1964) reported similar results with rain, dew, and mist on more than 100 plant species. Since some of the N in plant tissues is in mineral forms (NO_3 and NH_4-N) the quantity of which is reported to increase as a result of applying fertilizer N. In this experiment a loss of mineral N from plant tissues similar to that reported loss in K may have occurred.

Soil type and leaching losses:

The greater loss of mineral N by leaching from the fallow topsoil, compared with the fallow subsoil, is a manifestation of the greater organic N content (total N = 0·205 percent), organic matter (6%) and perhaps biological activity in the topsoil than in the subsoil (total N = 0·169%, 4% organic matter). On the other

hand the smaller leaching loss of fertilizer N from the fallow topsoil than from the subsoil may have been caused by a better retention of fertilizer N by the former than the latter. The amount of water passed through the unplanted soil column during the first 3 weeks when most of the leaching occurred, was smaller (365 ml.) from topsoil than (381 ml.) from subsoil. Owens (1960) found that loss of fertilizer N by leaching was positively correlated with the amount of water passing through the soil profile.

The texture of the soil effects retention of fertilizer N. The heavier topsoil lost smaller amount of fertilizer N than the lighter subsoil. Larsen and Kohnke (1946) demonstrated the effect of soil texture on leaching loss when 137 mm. precipitation removed all the applied fertilizer from a 58 cm. profile of a sandy loam whereas none from a silt loam. Other workers (Kolenbrander, 1969; Shaw, 1962) reported similar findings.

SUMMATION OF MINERAL N IN SOIL AND LEACHATE AND TOTAL N IN PLANT (Fig. 26)

During this experiment, mineral N in the soil + N uptake by the plant from the planted columns was greater than the mineral N content of the soil from the fallow columns with R_1 and R_2. This illustrates the preserving effect of the plant on mineral N in the soil against losses by immobilization and denitrification. This effect also occurred to fertilizer N. About 90% of the fertilizer N was lost from the fallow R_1 during this experiment compared with 50% from the planted columns. With R_2 the losses were 55% and 17% from the fallow and planted systems respectively. Leaving fertilizer N in a fallow soil would increase the risk of loss by immobilization and denitrification. The amount of fertilizer N recovered as mineral N from the fallow soil with R_1 and R_2 decreased progressively after the 3rd week, but that recovered by the plant and retained by the soil from the planted soil remained constant during this time and the total recovery was greater than that from the fallow.

When leaching occurred (With R_3) 30 - 100% of fertilizer N was removed in the leachates by the 7th week. There was no difference between fallow and planted treatments in the overall recovery of fertilizer N (i.e. in soil + plant + leachate). The distribution of fertilizer N on the fifth week was as follows:

50% in the plant, 32% in the leachate and 5% remained in the soil (planted topsoil); the remaining 13% was most likely denitrified and/or immobilized.

GENERAL DISCUSSION ON GREENHOUSE EXPERIMENT I

Movement of fertilizer N down the soil profile had already started by the 3rd week and this occurred with each of the water regimes (i.e. 60, 90, and 120% of water holding capacity). Down to the full depth of the columns (45 cm.), there was more mineral N in fertilized than in the unfertilized columns. The movement of mineral N down the profile is illustrated by the increase of mineral N with the increase in depth.

Because of its higher organic matter content, the topsoil had a higher mineral N content than the subsoil. Since on the 7th week there was a lower recovery of fertilizer N from the fallow topsoil than from the fallow subsoil with R_1 and R_2, immobilization and denitrification must have been greater in the topsoil.

About 50% of the fertilizer N was recovered from the subsoil in the 3rd week after application of fertilizer: the recovery was almost the same on the 7th week. The chemical and biological processes responsible for this low recovery had perhaps reached their maximum activity in the subsoil by the 3rd week.

The small difference in N uptake between plants in fertilized (60 kg N/ha) and unfertilized treatments of the subsoil was due to poor plant growth in the subsoil.

The proportion of fertilizer N recovered from R_1 and R_2 during this experiment varied with time suggesting a release to the soil of part of the N previously taken up by plant. This is shown by the topsoil in particular since plants removed a considerable proportion of fertilizer N. In R_1 and R_2 recovery of fertilizer N fluctuated from 70% on the 3rd week to 35% on the 5th week and 50 - 70% on the 7th week. The excretion of fertilizer N from plant to soil is further substantiated by the results of fertilizer N shown by the planted R_1 topsoil during the course of experiment: On the 3rd week 28% of fertilizer N (based on the difference in N contents between fertilized and unfertilized soils) was present in the soil; on the 5th week there was 55% but on the 7th week none of it was left.

When leaching occurred (R_3), about three quarters of the fertilizer N moved out of the soil columns. Excessive watering removed not only that part of fertilizer N remaining in the soil but also most of that which had been taken up by plant. This is shown by the topsoil in particular. About 30% of fertilizer N was leached from the system during the first 5 weeks of the experiment, and plants held 50% of it while 5% remained in the soil. The amount of water applied by that time was 744 mm precipitation. With more watering during the succeeding 2 weeks (271 mm more), 82% of the fertilizer left the system to the drainage water, none of it remained in the soil and only very little (less than 2% of it) was held by the plant. A similar

situation occurred in the subsoil system: following a recovery by plant of 33% of fertilizer N on the 3rd week, less than 2% was still remaining in plant by the 7th week.

THIRD:

GREENHOUSE EXPERIMENT II:

Effect of Soil Organic Matter on the Availability of Fertilizer Nitrogen

- Effect of Ignition on Mineral N contents in the soil
- Contents of Mineral N in Fallow Soil.

  Possible transformation of fertilizer NO_3-N in ignited soil.
  Possible transformation of fertilizer NO_3-N in unignited soil.
- Planted Soil

  Contents of mineral N in soil
  N Uptake
  The role of roots in N Uptake
- Effect of Cropping on the Recovery of Fertilizer N

EFFECT OF IGNITION ON MINERAL N CONTENTS IN THE SOIL

An increase in the contents of mineral N occurred as a result of ignition, and this increase was all in the NH_4-N fraction. The NO_3 content decreased on ignition. The following table gives the concentration of NO_3 and NH_4 in the soil before and after ignition:

	Unignited	Ignited
	ppm N	
NO_3-N	9·0	6·0
NH_4-N	7·5	18·0
Total (NO_3 + NH_4)	16·5	24·0

This increase in NH_4-N could be due to the following effects:

1. De-amination of some amino acids, amines, and proteins into NH_4-N during the process of ignition, and the retention of the NH_4 by the colloidal complex of the soil.
2. A decrease in the capacity for soil minerals to fix NH_4-N; and as a result, the release of fixed ammonium. Chaminade (1965) obtained an increase in NH_4-N as a result of subjecting clay to temperatures between 200 and 500°C. He attributed this to a 'desorption' of fixed NH_4 as a result of high temperature.

I CONTENTS OF MINERAL N IN FALLOW SOILS (Fig. 27)

The greater NO_3-N content in the unignited soil compared with the ignited soil at the end of the experiment would have been due to a greater nitrification in the unignited soil with its higher organic matter content. On the other hand, the lower NH_4-N contents in the unignited soil compared with the ignited could be due to the following reasons:-

1. A release of NH_4-N from the soil organic matter on ignition
2. A greater utilization of NH_4 by micro-organisms in the more biologically active unignited soil.

However, despite the unignited soil having less mineral N at the start of the experiment than the ignited, the control soils of both had similar contents of mineral N at the end of the experiment (40 days). Mineralization of organic N in the unignited soil was most likely responsible for the increase in mineral N during the experiment. The contents of mineral N in the ignited soil between the start and the end of the experiment was decreased by 9%. On the other hand there was a 14% increase in the mineral N content in the unignited soil between the beginning and end of experiment.

The difference in NO_3-N content between ignited and unignited soil was greater in the presence of fertilizer N than where N was not added. This suggests that more of the applied NO_3 must have undergone transformation to other forms in the ignited than in the unignited soil.

a. Possible transformation of fertilizer NO_3-N in ignited soil:

Ignition reduced the organic matter content of the original soil to almost zero, increased the mineral N content and reduced its biological activity. Therefore the transformations of fertilizer NO_3 would be of a chemical rather than biological nature. However, the possibility of some biological activity by surviving micro-organisms cannot be entirely ruled out. The most obvious chemical process which would cause the recovery of NO_3 from the ignited fertilized treatment to be lower than that from the unignited would be a chemical reduction of added NO_3. The low apparent recovery of fertilizer nitrogen (Fig. 31a) suggests a possible loss of fertilizer nitrogen from the mineral pool to some other forms.

A reduction of fertilizer NO_3 into ammonia is unlikely since the contents of exchangeable NH_4 were similar in fertilized and unfertilized soils. The higher NO_2^- content in the ignited soil, compared with the unignited, at the end of experiment suggests that reduction did take place. There was 0·05 and 0·30 ppm of NO_2-N in the unignited and ignited soils respectively.

Ignition might have released some metallic cations which had formed chelates with the organic matter. These cations released in an active state might have acted as catalysts in the chemical reduction of NO_3. Wullstein and Gilmour (1964) and Chao and Kroontje (1966) reported that the transition metals (Fe, Co, Cu, and Mn) were involved in the chemical reduction of NO_3 into N_2. Cawse (1969) showed that following soil sterilization by gamma irradiation NO_3-N, added after irradiation, was reduced to NO_2^-.

In addition to chemical mechanisms, this worker considered that some enzymatic systems which could have survived sterilization might have been responsible for the reduction. In the present investigation a similar situation may have occurred and denitrifying enzyme systems may have survived the heat of ignition and subsequently contributed to the reduction of added NO_3.

However, whether chemical or enzymatic, the formation of NO_2 ions from NO_3 in the ignited soil would lead eventually to the gaseous loss of nitrogen either by combining with NH_4 abundant in the ignited soil, or decomposition of the NO_2-ions, forming ammonium nitrite, NH_4NO_2. Allison (1963) attributed loss of nitrite nitrogen in soils, mainly to formation and dissociation of NH_4NO_2. Bulla et al. (1968) reported that NO_2^- compounds undergo degradation into N and nitric oxide in a sterile soil by a non-biological route. Khan and Moore (1968) studied denitrification of added fertilizer nitrogen in mineral and organic soils and reported that greater amount of elemental nitrogen were evolved from the mineral than from the organic one; 75 - 94% of added NO_3-N was denitrified from the mineral soil as compared with 65% from the organic one. They considered reductive chemical mechanisms to be of pronounced importance.

b. Possible transformation of fertilizer NO_3- in unignited soil:

Since the unignited and the ignited soils each gave a low apparent recovery of fertilizer N (Fig. 31a), fertilizer N must have undergone

a transformation into other forms of nitrogen in both soils. As the unignited soil was not deprived of its organic matter and unsterilized, the process in this soil could be both biological and chemical. Therefore fertilizer NO_3 in the soil could have taken any of the following possible pathways:

1. Immobilization:

The addition of fertilizer nitrogen may have stimulated microbial activity and resulted in a greater utilization of N (Chu and Knowles, 1966; Jansson, 1958; Vlehlova, 1963). Despite the greater mineralization of soil organic N from the unignited than from the ignited soil (see Fig. 27, unfertilized soils) a rapid immobilization might have occurred. Peshakov (1962) and Steinbrenner (1963) reported that mineral N application resulted in an increase in numbers of micro-organisms, particularly those utilizing N: this could have occurred in this experiment. It has been shown by Broadbent (1965) and Smirnov et al. (1968) that a proportion of fertilizer N ranging from 2 to 33% could be immobilized in organic forms. Stojanovic and Broadbent (1956) demonstrated that immobilization could occur to added fertilizer N as quickly as 2 - 6 days following application. MacVicar et al. (1951) attributed the low recovery of fertilizer N to immobilization.

The likelihood of an increase in the mineralization of organic matter indicated by abundant formation of NH_4-N, as a result of the application of fertilizer NO_3 (Broadbent and Stojanovic, 1952; Andreeva and Shcheglova, 1966; Saric and Miskovic, 1967) was not observed in this experiment where the NH_4-N content was similar in

fertilized and unfertilized soils. However, this increase might have been counterbalanced by a rapid assimilation by the additional micro-organisms which seem (Jansson, 1958; Jansson & Clark, 1952; Broadbent, 1966; Overrein, 1967) to prefer NH_4 to other mineral sources of N.

2. Denitrification

Anaerobic conditions were kept to a minimum by taking the following precautions during the experiment:

a. The soil was mixed with half its weight of coarse sand
b. Moisture content was maintained at 60 per cent water holding capacity.

However, denitrification of applied NO_3 may have taken place due to the following:-

(i) The introduction of NO_3 may have encouraged the proliferation of denitrifiers. This was reported by Legg et al. (1966) who found that the number of denitrifiers increased with an increase in the concentration of NO_3 and was more pronounced in the fallow than in the planted soil.

(ii) There may have been anaerobic pockets in the soil, at least temporarily, thus making denitrification possible. Greenland (1962) recorded losses by denitrification of up to 25% from soils maintained at 70 per cent W.H.C. He attributed this to the temporary occurrence of localized anaerobic pockets.

3. Reduction of NO_3

Reduction of NO_3 to elemental N or its gaseous oxides may have taken place chemically due to the effect of clay minerals or

transition metals (Wullstein and Gilmour, 1964; Wullstein, 1967); or by chemo-denitrification (Clark, 1962) when NO_2^- - which is likely to be formed from NO_3 by biological denitrification - undergoes chemical transformation leading to loss of elemental N. Losses of up to 30% of fertilizer NO_3 have been found in laboratory and pot experiments under conditions considered aerobic (Greenland, 1962; Walker et al., 1958; Wagner and Smith, 1958; Smirnov et al., 1958; Andreeva and Shcheglova, 1968; Khan, 1968).

Considering those 3 possible pathways of transformation of applied fertilizer NO_3, the assimilation of fertilizer nitrogen in the bodies of the soil micro-organisms - immobilization - is not necessarily the only reason for the low recovery of fertilizer nitrogen from the unignited soil. A degree of biological denitrification, chemo-denitrification, or chemical reduction of NO_3 is likely to have occurred in the unignited soil.

In conclusion, between 41 and 45 percent in the unignited soil and 45 and 58 percent in the ignited soil, of the added fertilizer NO_3 was converted to non-mineral forms in the presence and absence of native organic matter of the soil respectively. The mechanisms are most probably of a chemical nature in the absence of organic matter and a combination of chemical and biological mechanisms in the presence of native organic matter and micro-organisms. From the lower apparent recovery of fertilizer NO_3 shown by ignited soil (compare the two soils Fig. 31a) it seems that nitrate reduction by chemical means could be important.

II PLANTED SOIL

1. Contents of mineral N in soil

The smaller content of mineral N in the planted soil compared with the fallow, at the end of the experiment demonstrates the effect of plant on N uptake. The difference was more remarkable where fertilizer was applied.

The similar contents of mineral soil N in each of the 3 nitrogen treatments at the end of the experiment indicates that no fertilizer nitrogen remained in the mineral form. Data published by Gasser (1962) showed that there was similar concentration of mineral N in fertilized and unfertilized soils following one year of wheat.

This suggests that most of the applied fertilizer which remained in mineral form was easily removed by plant roots. It is probable that there is a state of equilibrium existing between the soil and its mineral N content, producing for a given soil a certain fixed level of mineral N; any excess will be easily removed from the soil. When the level falls below this 'fixed' value (by removal in plants, microflora or otherwise) either (a) the availability of mineral N becomes exceedingly difficult, or (b) the soil reacts by restoring its mineral N content to that level.

In this experiment, the soil was perhaps in a state of equilibrium before pllying fertilizer N. At the end of plant growth: (a) the similar contents of mineral N in the no N and N planted soil (Fig. 27) and (b) the small difference in the contents of mineral N in the fallow no N and their planted counterparts may be explained by the existence of this critical level of mineral N at

the beginning of the experiment. This state of equilibrium is similar to the 'dynamic equilibrium' theory of Bartholomew and Janssen (1931) and tested by Chaminade (1934) and Schachtschabel (1937) in which a possible equilibrium between fixed, exchangeable, and soluble K in soil is suggested. Nommik (1957) applied this theory with regard to NH_4-N and presented (Nommik, 1965) a schematic equilibrium involving free soluble-, adsorbed exchangeable-, and fixed-NH_4-N.

There was little difference in mineral soil N between treatments in the planted system but large differences are displayed in the uptake of N by plants.

2. N uptake

The greater uptake of N by plants from the unignited soil, compared with the ignited, was mainly due to the greater uptake in roots from the unignited soil. This in turn is associated with a greater root growth in the unignited soil and may be (Fig. 32 Plate 13) due to one of the following possible explanations:

a. More NO_3-N was produced from the unignited than from the ignited soil as indicated by the results of the fallow treatment (Fig. 27a)

b. The high concentration of NH_4-N in the ignited soil and its consequent adverse effect on root growth. The oxidation of soil organic matter is bound to decrease the buffering capacity of the soil and consequently accentuates the retarding effect of the abundant NH_4 on root growth. Bennett et al. (1964) studied the effect of NH_4- and NO_3-N in a low buffering growth medium (pure

sand) on the growth of maize seedlings. They reported a toxicity effect on plant roots as a result of NH_4- application at rates ranging from about 6 ppm to 112 ppm.

c. A possible mildly toxic effect, of a temporary nature at the beginning of the growing period on plants grown in the ignited soil due to an increase in cations of heavy metals or toxic organic compounds Warcup (1957) reported that an increase in the concentration of cations, particularly soluble Mn. as a result of subjecting the soil to steam sterilization may retard root growth of the plant. Rovira and Bowen (1966) on the other hand concluded that the formation of some toxic organic materials, formed by heating the soil to 120°C, may result in retardation of root growth.

One or more of the above-mentioned reasons was responsible for the smaller root growth in ignited as compared with unignited soil. Observations taken on the 11th day after sowing showed that there was a retardation in plant growth which may have contributed to the lower uptake of N by plants grown in ignited soil. On that day there were only 2 seedlings per pot emerged in ignited as compared with 6 in the unignited soils.

With application of fertilizer to either soil, N uptake increased, the increase was nearly proportional to the rate of fertilizer application. While treatments receiving 4·9 mg. NO_3-N/pot gave an increase over the control of 3·9 and 3·7 mg. N/pot for ignited and unignited soils respectively, the increase was nearly twice as great, viz. 7·4 and 7·8 mg./pot respectively at the N_2 level (9·8 mg. NO_3-N/pot). The greater root growth of fertilized plants compared

with those of the control (Fig. 32, Plate 13) would be partly responsible for the greater removal of N from fertilized pots than unfertilized. Despite the rather small difference in root growth between N_1 and N_2 the plants receiving the higher rate of fertilizer NO_3 removed far greater N than those supplied with the lower rate.

3. The role of roots in N uptake

It follows from what had just been written about the extension and expansion of root growth in fertilized soil that plants were able to increase their uptake of N from the soil due to the increase in the volume of roots as well as the increase in available N. Cornforth (1968a) reported that increasing the volume of soil explored by plant roots resulted in greater root extension as well as N uptake. However, in this investigation the difference in root extension could not be the only reason behind the difference in N uptake by plant, since, with nearly the same root system, plants in the N_2 treatment were able to remove twice as much nitrogen as those in the N_1. The results emphasize the important effect of the quantity of available N on N uptake and on yields of tops rather than on the expansion of roots. The restriction on root growth induced by the limited volume of pot especially in fertilized plants did not reduce their capacity to remove available nitrogen, transforming the extra to plant tops, the yield of which increased with increase in N rate (Fig. 32, plate 13). This is reflected in the increase in the ratio of N uptake by tops to that by roots (Fig. 29) and which is in agreement to those ratios reported by Walker et al. (1956).

The effect of the availability of fertilizer nitrogen and the subsequent removal by plants is demonstrated by the findings published by Henzell et al. (1964) who showed a pronounced increase in N uptake by plant with the increase in rates of applied N ranging from 0 to 200 ppm. While there was a small difference in the quantity of N contained by roots of the different treatments, it was in tops that the differences were most remarkable. Roots contained from 1 to 5 me. N/pot while tops contained from 2 - 22 me. N/pot. This was also reflected in the ratios of N uptake by tops to that by roots reported by these investigators; the reported ratios ranged from 0·4:1 up to 5:1 increasing with the increase in the rate of fertilizer N application.

The greater N uptake by plants in the presence of soil organic matter (unignited soil) than in its absence (ignited) - Fig. 28 - is a manifestation of the following:

a. Mineralization of organic N from the reservoir of soil organic nitrogen.

b. A better conservation of fertilizer NO_3 in the unignited soil compared with the ignited. Although the transformation of fertilizer NO_3 to other forms (organic or gaseous) may have occurred in the unignited soil, it seems that this occurred to a lesser extent in the unignited soil; the exclusion of fresh bulky plant residues (stubble) from the soil during preparation of soil (sieving through 2 mm. sieve) might have reduced the extent of net immobilization.

III EFFECT OF CROPPING ON THE RECOVERY OF FERTILIZER N (Fig. 30)

The effect of cropping on the removal of soil N and on the recovery of fertilizer N is demonstrated by the total available N in the two systems (Fig. 30).

In unfertilized pots, the planted system showed a higher recovery of available N over that in the fallow. This suggests that plants must have removed some forms of nitrogen which could not be recovered - in mineral forms - in the soil extracting solution. These forms could be:

a. Fixed NH_4-N

It was reported by Monem and Nasseem (1967) that plants are capable of removing about 27% of the fixed NH_4-N from the soil.

b. Some amino acids.

Some organic forms of nitrogen can enter plant roots. It was reported by Scheffer et al. (1967) and Yatazawa et al. (1968) that plant roots are capable of removing some amino acids.

On the other hand the greater recovery of N displayed by planted over fallow fertilized treatments would suggest the following:

a. A conserving effect of plant roots on fertilizer NO_3:

The presence of plant roots may have acted as a catching agent conserving fertilizer N by removal into plant tissues and thus decreasing the extent of losses occurring to available fertilizer N in the soil. This is supported by the far greater N uptake by plant tops in pots receiving the higher rate of N over those receiving the lower one despite the very slight difference in root yields.

Yoshida (1966) reported a rapid translocation of nitrate from roots to leaves as compared with NH_4-N.

b. A smaller loss of available fertilizer NO_3 by immobilization:

The presence of roots and their greater effect on microbial activity (Katznelson and Bose, 1959; Goring and Clark, 1949; Bartholomew and Clark, 1950) in planted than in fallow systems may have resulted in a lower net immobilization in planted as compared with fallow. A similar result was reported by Smirnov et al. (1968) where 11 and 33% of fertilizer nitrogen were immobilized in planted and fallow soils respectively in the present investigation, it was in the presence of plants that unignited soil displayed greater recovery of available N over the ignited one. This emphasizes the effect of plants in decreasing the net immobilization which may occur to fertilizer nitrogen.

GENERAL DISCUSSION ON GREENHOUSE EXPERIMENT II

Ignition of soil seemingly eliminated organic matter and most certainly sterilized the soil, liberated a considerable amount of immobilized and 'fixed' forms of N to mineral forms of N, mainly NH_4-N.

The increased contents of mineral N during the 40 days of the experiment which occurred in unignited soil but not in the ignited reflects the effect of biological activity in mineralization of soil organic N.

The low recovery of fertilizer N at the end of the experiment occurred in both soils. It seems that applied fertilizer N underwent transformations which, in ignited soil, were mainly of chemical - rather than biological nature - leading to some losses. Reduction of fertilizer NO_3-N, perhaps catalyzed by heavy metallic cations - in the absence of chelating organic substances may have been involved. The presence of the plant in ignited soil seemed to have counteracted this reduction process by removal of a considerable part of mineral N into its tissues. There was a substantial increase in the apparent overall recovery (soil + plant) of fertilizer N in the presence of plant: recovery increased from about 50% in fallow to 80% in planted ignited soil.

In unignited soil, immobilization seemed to have been the main channel responsible for the low recovery of fertilizer N in both fallow and planted soils. Plants helped to increase the

recovery of fertilizer N, perhaps by removing abundant mineral N which would have been subject to immobilization. Recovery increased from about 60 to 82% by planting the soil.

There was an initial retarding effect on growth of plants at the beginning of growth in ignited soil, probably due to the effect of heavy metals.

There may have been a critical level of mineral N above which it is easily removed without the soil compensating it, but below which soil restores it.

FOURTH:

LABORATORY EXPERIMENT:

"Effect of Aggregates Size on Leaching Loss of NO_3-N"

Contents:

. Fertilizer N and leaching from soil.

. " " and its effect on soil N.

. N mineralization and aggregate size.

. Retention of fertilizer N by soil and sand.

DISCUSSION

FERTILISER NITROGEN AND LEACHING FROM SOIL:

Almost all the added NO_3-N was leached from the soil aggregates. The difference in the pattern of leaching from large and small aggregates (Fig. 34), suggests different methods of retention of fertiliser N in the two aggregates. Two stages of leaching will be discussed here. Within each stage the behaviour of large aggregates relative to the small ones was consistent.

1. First stage: Leachates I to IV:-

From the start of leaching till the fourth leachate, fertiliser NO_3-N was more easily leached from the small than from the large aggregates. The method of fertiliser application and of watering may have been responsible for this difference.

Following the application of K NO_3 to the surface of the air dry soil aggregates, sufficient water was applied, initially to moisten the soil, without allowing leaching. Therefore the dissolved salt was retained largely inside the soil aggregates. NO_3-N in the interior of aggregates is more likely to be leached from small than from large aggregates.

Weirsum (1962) and Cornforth (1968b) reported a smaller uptake of N from large than from small aggregates: inaccessibility of NO_3-N in the inner-pores of large aggregates was suggested by Cornforth (1968b). A similar suggestion was put by Cunningham and Cooke (1958) who stated that NO_3-N inside structural units is not easily leached.

In this experiment the smaller loss by leaching from large than from small aggregates (in the first stage) may have been due to greater retention of mineral N by the large than small aggregates. Another factor could be the larger surface area of small aggregates. Holt and Timmons (1967) reported that the concentration of mineral N is greater at the surface of aggregates than in the interior. The loss of mineral N from unfertilised soil (Fig. 34a) during the experiment was greater from the small than from the large aggregates.

2. Second stage: Leachate V to X:-

The small aggregates of the unfertilised soil continued to give up more N than the large aggregates. With the fertilised soil, more NO_3-N was lost from the large than from the small aggregates. This change indicates a difference in retention of fertiliser NO_3-N, perhaps caused by the movement of fertiliser N from the inside to the outside of aggregates. Between waterings (time interval varied from few hours to 1 - 7 days, see Table 4 page 53), the soil would become drier and this would cause movement of water from the interior outwards carrying NO_3-N nearer the surface. Sharma & Uehara (1968a & b) reported that movement of water from the inside of soil aggregates becomes greater as the moisture content of the soil decreases.

Summing up the two stages, at first fertiliser N was retained to a greater extent by large aggregates; then percolating water removed that part retained earlier on, thus rendering more fertiliser N lost by large than small aggregates.

FERTILISER N AND ITS EFFECT ON SOIL N:

The large apparent recovery of fertiliser nitrogen (99 - 100%) suggests that almost all the added NO_3-N remained in a mineral form. About 80 percent was removed from the soil within 10 days giving little time for biological fixation.

However, the addition of fertiliser nitrogen seemed to influence the transformation of soil nitrogen for there was more NH_4-N in fertilised than unfertilised treatment (Fig. 34a). This suggests an increase in the mineralization of organic N following the application of NO_3-N and/or a release of NH_4^+ by the K^+ associated with the NO_3^- of the fertilizer.

Broadbent and Stojanovic (1952) and Hauk (1968) reported an increase in NH_4-N as a result of NO_3-N application. Broadbent (1965) attributed this to a breakdown of cells by the added salt - releasing protoplasmic N for mineralization. This theory may apply to this investigation. Ivanson et al. (1970) reported an increase in the amino acid contents in the soil as a result of the application of nitrogenous fertilizer.

N MINERALIZATION AND AGGREGATE SIZE:

Small aggregates gave up more NH_4-N than large aggregates where no fertilizer N was applied. It would appear that mineralization of N is greater in the smaller aggregates. This may have been caused by:

(a) a higher moisture content in the small aggregates;

Waring and Bremner (1964) and Miller and Johnson (1964) reported

that high moisture content favours NH_4-N mineralization. Waring and Bremner (1964) showed that the formation of NH_4-N in waterlogged soil was far greater than in aerated soil.

(b) a higher organic N content in small aggregates. Wittmuss and Mazurak (1958), Tabatabia and Hanway (1968) reported an increase in organic N content with the decrease in the size of soil aggregates.

RETENTION OF FERTILIZER N BY SOIL AND SAND:

The conserving effect of soil aggregates on fertilizer N against immediate leaching is demonstrated by the small proportion of fertilizer N (7%) leached initially from the soil columns compared with well over 95% collected from the sand columns.

CONCLUSION

The dissolved K NO_3 migrates towards the interior of aggregates. This results in a greater retention of NO_3 by large than by small aggregates. After continuous leaching, almost all the added nitrogen was leached from soil aggregates.

VI. GENERAL DISCUSSION ON FATE OF FERTILIZER N EXPERIMENTS

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Fertilizer N remaining in the soil undergoes changes. Its complete removal by plant secures it from such transformations. After its solution in the percolating water, fertilizer N moves down the profile: this is indicated by the greater mineral N content of the fertilized over the unfertilized horizons down to 60 cm. Within 3 weeks 18 - 43% of the autumn applied fertilizer moved into the 30 - 60 cm. horizon of fallow soils. The rainfall responsible for that movement was not excessive, (only about 38 mm.). Nevertheless, this amount clearly illustrates the speed at which the fertilizer is translocated from the surface to the subsoil. Plants, although still very small, partially retarded the downward movement. When fertilizer N appeared 60 cm. down in the fallow soil, it had not gone much further than 45 cm. in the planted one.

Precipitation and irrigation above a certain level could remove all the fertilizer nitrogen if high enough, and if no counter-mechanisms are provided. Irrigation equivalent to 482 mm. water was enough to remove almost all the fertilizer N from 45 cm. soil profile but only about one third when the soil had a plant cover of active growth. Only three months after the autumn application of fertilizer N, there was none of it, measurable as mineral, down to 60 cm. This removal of mineral fertilizer N beyond the 60 cm. profile was caused by the 157 mm. rainfall during that period. A precipitation of a similar amount (136 mm.) in the summer during a similar period ($2\frac{1}{2}$ months) following the spring application of fertilizer N did not result in a

similar movement. Up to 52% of the fertilizer N was present in mineral form in the 60 cm. fallow soil profile. The higher summer (compared with winter) evaporation of water from the soil must have counteracted the downward movement of fertilizer N.

The only means of judging the leaching loss of fertilizer N in this investigation under field conditions was the study of the change in the mineral N with depth and time in fertilized and unfertilized plots. The magnitude of leaching loss was demonstrated in the greenhouse investigation through the application of watering to soil columns and measuring the quantity of mineral N in leachates. Within 7 weeks, and 1025 mm. water, planted and fallow columns lost to the drain more than 75% of the applied fertilizer. This shows that plants could not entirely hold fertilizer N against leaching, if precipitation is high and persistent enough.

Under field conditions, the variation in the extent of leaching (projected through the variation in mineral N content with depth) is due to the variation in the soil. These variations are most likely to be in both chemical and physical properties. The proportion of large stones varied from one soil core to another and from one plot to another. The most effective way to minimise this effect is to increase the number of replicates rather than the number of soil cores per plot.

For the plant to decrease effectively the leaching losses, plant should be in an active phase of growth and uptake of N at the time of application. There was a sizeable leaching loss of fertilizer N when the plant was growing slowly during December to

May, but during vigorous and active growth there was little fertilizer N in the soil. Fertilized and unfertilized soils showed no difference in mineral N content in their horizons in July (nearly $2\frac{1}{2}$ months after application of as much as 90 Kg. NO_3-N/ha). During this May to July period the N uptake by plant increased 3 to 24 times. This increase in N-removal by plant resulted in little loss by leaching or by denitrification. In June, N uptake from the fertilized treatments (60 and 90 Kg. NO_3-N/ha applied in May) were similar. In July the uptake of plants on the higher rate was nearly 30 Kg. N/ha more than that on the lower rate. In the soil itself, on the other hand, there was no fertilizer N (as mineral) remaining in the soil from June onwards. Since uptake was measured in above-the-ground plant parts, plants perhaps removed the spring applied fertilizer N by June but its translocation from roots to tops was complete by July.

For plant roots to remove fertilizer N which has been leached down the soil profile they have to reach that part of the fertilizer which moved downwards. This means that the two main pathways of fertilizer N, i.e. uptake and leaching, are intricately related: maximum fertilizer N uptake is possible only if there is a fair degree of diffusion of fertilizer in the soil. The root system of the plant is not confined to the 0 to 30 cm. horizon of the soil. There was a vigorous root mat between 50 to 75 cm. (see plate 10) and at least 30% of the root system of fertilized plants extended beyond the 30 cm. depth of soil. Between these

(50-75cm)
depths the root mat has prevented loss by leaching of fertilizer N which moved to the subsoil. As shown in the greenhouse experiment II, the root systems produced by N_1 and N_2 had similar weights (Fig 32) but N uptake from the N_2 treatment was much greater than from the N_1 (Fig. 28).

In the absence of plants or when their growth is very small, fertilizer N is also lost by biological and chemical means in the soil. The main criteria for estimating these mechanisms is the study of the change in mineral N content with time, taking the soil moisture content into consideration. Topsoil was compared with subsoil and with ignited topsoil in that respect.

Three months after fertilizer application in the autumn, topsoil in plots which received fertilizer N had smaller content of mineral N than those which had received no fertilizer N. This happened in most of the fertilized treatments. It shows that, not only did immobilization occur to fertilizer N, but also it was accelerated by the application of fertilizer. This topsoil immobilized about 88 percent of fertilizer N within 7 weeks when soil was kept under regimes not conducive to significant denitrification. Further elucidation of immobilization was obtained during the spring and summer; There was 50 percent recovery of fertilizer N from the fallow plots in June; the remainder of it was not completely lost from the systems by leaching or denitrification. There was a moisture deficit in the soil at that time as evapotranspiration exceeded precipitation (see Fig. 21c); and the content of mineral N in the 30 - 60 cm. subsoil of the N plots was only 1 - 4 Kg.N/ha (i.e. less than 5% of the amount applied) more than that in the no-N. Therefore, about one

half of the applied fertilizer had been immobilized by the soil micro-organisms in about four weeks (by June) during the summer (15 to 20°C soil temperature, Fig. 22). In July with a greater moisture deficit (i.e. less conducive to denitrification) and warmer soil conditions (17 to 21°C), immobilization must have been largely responsible for the small recovery (37%) of fertilizer.

However, immobilized fertilizer N is not entirely lost from the system since there is a possibility of its being remineralized. The greater (about 50 Kg. N/ha) uptake, at the end of the 9 months growing season, by all plants which had received the greater autumn rate compared with the lower rate is most likely caused by remineralization. That part of the autumn applied N which was immobilized within 3 months after application became available to plants after mineralization.

Whether or not the presence of living plant roots enhances immobilization of fertilizer N could not be investigated satisfactorily in this experiment. However, living plant roots seemed to have encouraged biological activities in the soil. In February in two out of four cases fertilized soil contained 12 - 95 Kg./ha less mineral N in planted than in fallow plots. This difference could not have been accounted for in the plant tissues. At this time uptake was less than 2 Kg. N/ha in above-ground parts. Even allowing for the uptake by roots (in a 1:1 ratio of roots: tops uptake of N) this would still not make up for such a difference. The rate of immobilization must have increased by application of fertilizer.

Microbial reduction of NO_3-N during the winter months had, most likely, taken place. The increase in NH_4-N content in fertilized plots in particular could be considered as an indication of this.

The part of fertilizer N which moves down to the mineral subsoil must have undergone reduction by chemical as well as biological means. There was no plant litter in the 30 - 60 cm. subsoil whereas there was in the 0 - 30 cm. topsoil. The chemical reduction of fertilizer NO_3-N to N_2 was indicated by results of the subsoil columns and in the ignited soil when as much as 60% of applied N was not recovered from these treatments.

VII. CONCLUSIONS

CONCLUSIONS

The results obtained in this investigation show that movement of fertilizer N from the soil surface is the first step which leads to the various pathways that fertilizer N takes. Such a movement brings fertilizer N in contact with agents (micro-organisms, plant roots, chemical compounds) which affects its state in the soil.

When fertilizer N reaches the drains it is lost from the system. A precipitation of about 160 mm. during the winter period was enough to leach the part of fertilizer N which was still in mineral form completely from the 60 cm. soil profile. Leaching was the main cause of loss of fertilizer N during the winter. However, during the summer, more precipitation is needed to exert leaching loss.

The recovery of fertilizer N by plant uptake was as much as 75 percent in field experiments and even more (95%) in pot experiments.

The low temperature during the winter did not seem to retard immobilization of fertilizer N. The considerable formation of NH_4-N in the soil after the application of fertilizer NO_3-N, indicates immobilization, although it could also indicate enhancement of mineralization.

About 40% of fertilizer N seemed to have been immobilized during 5 weeks under 25 - 40°C and 60% water holding capacity.

Denitrification was largely responsible for the disappearance of about 80% of fertilizer N during the same period under the same temperature but with a higher moisture content (90% of W.H.C.).

Reactions leading to gaseous loss of applied NO_3-N are indicated by the low recovery of fertilizer N from both the highly mineral subsoil and from soil ignited to destroy its organic matter and reduce biological activity.

Under field conditions, denitrification and reduction of fertilizer NO_3-N to N_2 in the subsoil seems to act on the downward moving fertilizer N, consequently only a small proportion of it reaches the drain.

The retention of fertilizer nitrogen against rapid loss by leaching is helped by soil aggregates particularly when the soil is dry before application. Fertilizer N is absorbed in the interior of aggregates; subsequently persistent rain is required to remove it to the drains.

It is inevitable that part of applied fertilizer N will be lost through denitrification, leaching, or immobilization. At a certain time, the only way to ensure maximum uptake of fertilizer N is to provide plants with the exact amount of N they are capable of removing from the soil at that time. For this reason, application of fertilizer N should be done so as to allow the shortest time between its introduction to the soil and active removal by plant. This would reduce the effect of other competing processes (immobilization, denitrification, and leaching). Fertilizer N was totally recovered in leachates by a persistent high precipitation showing that a continuous removal of it by leaching left none for other competing mechanisms (micro-organisms, plants).

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X : APPENDIX .

Contents.

Table 1 : Field Experiment; contents of NO_3- &NH_4- N in soil.(kg./ha.)

Sampling 1 (Dec. 1968)

FALLOW

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	31.0		56.0		48.1		51.2		46.0	
H2	21.2		33.0		36.3		33.1		30.3	
H3	6.6		11.9		15.6		12.9		14.2	
H4	2.8		6.6		8.9		5.7		9.4	
Total	61.6		107.5		108.9		102.9		99.9	
					NH_4-N					
H1	23.0		31.2		18.1		40.6		38.1	
H2	25.3		30.0		15.6		35.5		34.5	
H3	20.1		29.9		34.4		35.7		26.2	
H4	17.0		27.5		33.6		27.5		21.5	
Total	85.4		118.6		101.7		138.3		120.3	

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 2 : Field Experiment; contents of NO_3- & NH_4-N in soil.(kg./ha.)

Sampling 2 (Jan. 1969)

FALLOW

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	54.1	52.5	51.7	55.0	55.3	59.9	51.5	69.3	38.2	59.0
H2	29.5	54.6	31.2	51.0	33.9	59.6	75.7	55.3	27.4	38.9
H3	11.3	14.2	10.3	21.0	9.2	18.9	39.1	18.2	8.2	13.3
H4	4.9	9.2	2.1	9.8	3.1	19.1	12.0	11.7	4.2	8.3
Total	99.8	130.5	95.3	136.8	101.5	157.5	178.3	154.5	78.0	119.5
					NH_4-N					
H1	42.3	45.6	44.1	27.6	42.3	38.0	38.3	30.9	32.3	35.8
H2	33.2	42.8	29.6	32.8	33.9	37.9	42.0	39.2	36.0	32.1
H3	27.3	48.0	32.6	40.9	36.1	58.0	35.9	49.5	40.8	36.9
H4	19.8	37.4	24.9	47.5	28.4	50.8	41.1	47.0	32.8	26.8
Total	122.6	173.8	131.1	148.8	140.7	148.7	157.3	166.6	141.9	131.6

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 3 : Field Experiment; contents of NO_3- & NH_4-N in soil. (kg./ha.)
Sampling 3 (Feb. 1969).

FALLOW

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	62.6	71.6	50.9	47.5	61.7	35.2	21.6	55.5	58.6	67.4
H2	59.1	56.5	45.3	59.5	53.6	31.6	22.3	44.1	84.4	55.5
H3	25.3	21.5	18.4	27.0	23.4	25.1	22.4	24.3	26.2	22.4
H4	14.6	14.7	12.6	20.5	18.5	17.2	22.6	19.4	15.0	18.5
Total	161.6	164.3	136.2	154.5	157.0	109.1	88.9	143.3	184.2	163.8
					NH_4-N					
H1	7.3	12.3	9.3	17.1	14.4	18.9	11.8	8.7	16.4	14.3
H2	16.8	18.7	24.5	14.6	32.4	27.2	12.6	15.9	29.2	27.6
H3	51.5	28.9	51.8	45.1	42.7	42.8	19.4	39.4	58.2	38.8
H4	51.1	33.7	43.1	51.1	29.9	52.5	24.1	33.1	46.0	33.0
Total	126.7	93.6	128.7	127.9	119.4	141.4	67.9	97.1	149.8	113.7

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 4 : Field Experiment; contents of NO_3- & NH_4-N in soil.(kg./ha.)
Sampling 4 (May 1969).

FALLOW

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	20.4	56.4	20.5	66.6	18.6	51.0	11.9	51.7	8.4	53.6
H2	18.8	46.0	13.9	44.9	15.4	36.0	13.0	39.4	13.0	40.7
H3	11.2	12.8	8.2	10.2	8.1	14.4	13.3	14.1	10.8	13.2
H4	8.2	7.7	7.8	9.3	6.9	13.4	13.1	14.3	9.1	9.5
Total	58.6	122.9	50.4	131.0	49.0	114.8	51.3	119.5	41.3	117.0
					NH_4-N					
H1	43.1	50.0	34.4	47.2	55.8	70.9	38.7	47.2	36.8	39.9
H2	26.8	45.1	32.0	60.8	42.8	46.8	34.0	42.8	29.7	47.0
H3	21.5	43.1	29.6	47.9	19.4	34.9	25.8	45.7	25.7	36.6
H4	17.5	37.5	16.1	53.3	9.1	55.7	25.3	57.3	22.4	27.9
Total	99.9	175.7	112.1	209.2	127.1	208.2	123.8	139.0	114.6	151.3

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 5 : Field Experiment; contents of NO_3- & NH_4- N in soil.(kg./ha.)
Sampling 5 (June 1969).

FALLOW

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	19.5	23.4	48.5	44.1	59.2	54.1	47.6	41.5	45.1	48.3
H2	15.0	23.5	20.2	28.9	33.6	43.5	11.6	26.3	15.2	32.0
H3	5.7	11.0	5.7	14.0	9.3	14.3	8.3	9.8	7.8	11.8
H4	3.7	9.7	3.3	9.3	8.0	12.2	6.4	10.2	8.0	9.7
Total	43.9	67.6	77.7	96.3	110.1	124.1	73.9	87.8	75.1	101.8
					NH_4-N					
H1	19.3	38.3	41.1	36.0	44.8	35.8	18.9	42.8	15.8	22.7
H2	20.5	38.3	22.8	27.1	35.5	16.7	12.2	29.1	13.0	17.9
H3	20.1	28.6	19.7	23.2	20.0	13.7	9.1	25.3	9.6	14.6
H4	8.9	29.9	14.0	19.4	6.1	10.4	7.4	20.3	6.8	7.7
Total	68.8	135.1	97.6	105.7	106.4	76.6	47.6	117.5	45.2	62.9

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 6 : Field Experiment; contents of NO_3-N& NH_4-N in soil.(kg./ha)
Sampling 6 (July 1969)

FALLOW

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	14.8	14.3	24.5	28.2	49.0	57.0	27.2	29.8	34.0	55.4
H2	9.4	12.4	13.4	20.4	20.9	15.5	16.0	10.5	20.0	24.8
H3	5.9	5.9	5.8	10.3	5.9	8.9	7.7	10.4	9.5	11.1
H4	4.1	4.8	2.5	7.7	3.4	6.7	6.1	8.5	6.5	9.1
Total	34.3	37.4	46.2	66.6	79.2	88.1	57.0	95.2	70.0	100.4
					NH_4-N					
H1	10.9	14.4	9.5	26.7	21.3	19.0	7.6	18.4	10.8	33.0
H2	7.1	12.5	8.4	16.3	11.3	15.0	4.5	12.6	6.0	21.6
H3	4.1	6.8	5.7	12.0	6.4	10.6	3.4	8.2	4.6	14.8
H4	3.0	5.2	1.3	6.7	3.4	6.7	3.0	3.0	3.4	5.8
Total	25.1	38.9	24.9	61.7	42.4	51.3	18.5	42.2	24.8	77.9

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 7 : Field Experiment; contents of NO_3-N & NH_4-N in soil (kg./ha).
Sampling 7 (Sept. 1969)

FALLOW

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	31.6	30.4	37.4	36.6	58.7	35.4	35.4	55.1	41.5	53.1
H2	21.1	24.9	30.0	33.9	44.6	37.8	33.1	42.0	35.1	38.1
H3	8.9	9.2	8.6	14.2	15.7	15.5	17.3	15.1	18.4	14.7
H4	5.4	6.1	3.6	10.6	10.2	7.7	8.7	10.6	11.4	9.1
Total	67.1	70.6	79.6	95.3	129.2	96.4	94.5	122.8	106.4	115.0
					NH_4-N					
H1	33.9	75.6	44.7	27.9	39.6	18.1	47.3	57.4	60.0	49.7
H2	21.4	48.7	30.5	21.4	52.7	22.4	32.4	40.0	32.6	27.6
H3	14.1	21.8	20.8	22.9	15.6	15.3	28.6	29.4	13.4	18.7
H4	9.3	15.7	8.9	8.9	6.0	2.2	14.6	21.8	21.4	10.7
Total	78.7	161.8	104.9	81.1	93.9	58.0	122.9	148.6	118.4	106.7

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 8 : Field Experiment; contents of NO_3- & NH_4-N in soil (kg./ha.)

Sampling 1 (Dec. 1968)

PLANTED

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	35.3		50.3		74.1		67.0		67.6	
H2	28.7		39.5		42.2		35.2		33.1	
H3	11.3		10.3		9.3		13.8		6.5	
H4	6.4		3.9		2.6		5.4		2.7	
Total	81.7		109.0		128.2		121.4		109.9	
					NH_4-N					
H1	16.5		15.6		13.1		12.3		10.9	
H2	16.0		17.3		19.7		16.2		14.0	
H3	18.5		29.7		20.7		17.6		11.3	
H4	20.0		31.7		14.5		14.7		8.0	
Total	71.0		94.3		68.0		60.8		44.2	

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 9 : Field Experiment; contents of NO_3- & NH_4-N in soil (kg./ha.)
Sampling 2 (Jan. 1969)

PLANTED

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	42.3	54.9	60.5	55.8	67.6	58.9	56.6	52.1	43.6	72.1
H2	29.0	41.8	41.5	46.4	40.8	51.4	42.2	50.0	41.5	59.0
H3	8.8	13.9	13.9	19.8	14.4	17.4	13.3	18.2	9.4	27.3
H4	6.2	8.5	8.2	18.1	8.3	13.2	7.4	17.5	5.5	25.8
Total	86.3	119.1	124.1	140.1	131.1	140.9	119.5	137.8	100.0	184.2
					NH_4-N					
H1	49.4	44.1	29.5	30.6	35.9	30.1	51.5	29.5	35.8	40.0
H2	45.2	40.6	30.7	37.4	41.9	36.5	42.1	33.3	38.9	38.2
H3	38.3	42.9	26.0	44.4	44.9	36.3	38.9	34.1	31.8	39.8
H4	53.1	28.7	27.3	44.9	39.3	38.6	42.3	43.7	23.8	29.7
Total	186.0	156.3	113.5	157.3	162.0	130.5	174.8	140.6	130.3	147.7

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 10 : Field Experiment; contents of NO_3- & NH_4-N in soil (kg./ha.)

Sampling 3 (Feb. 1969)

PLANTED

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	58.1	62.7	70.4	20.4	43.5	14.2	30.5	76.5	20.8	45.8
H2	49.9	69.3	61.2	28.1	45.5	15.1	52.9	73.7	39.4	57.4
H3	19.3	29.4	38.8	27.5	24.7	27.7	28.0	40.1	21.0	25.6
H4	18.9	14.1	29.7	18.5	15.5	20.4	11.4	21.6	16.2	16.6
Total	146.2	175.5	200.1	94.4	129.2	77.4	122.8	211.9	97.4	145.4
					NH_4-N					
H1	11.5	9.7	7.6	19.8	11.1	17.4	11.0	17.4	14.4	15.0
H2	18.3	19.5	19.3	19.5	13.6	16.3	24.2	25.4	15.8	19.5
H3	44.7	45.3	47.2	24.9	35.7	20.5	37.6	55.7	24.4	42.0
H4	58.5	56.2	52.2	48.6	37.1	24.6	21.4	68.4	17.4	43.0
Total	133.0	130.7	126.3	112.8	97.5	78.8	94.2	184.9	66.0	119.5

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 11 : Field Experiment; contents of NO_3- & NH_4-N in soil (kg./ha.)
Sampling 4 (May 1969)

PLANTED

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	30.3	28.0	18.2	56.4	32.1	51.0	26.3	38.3	31.7	50.4
H2	20.7	18.9	13.9	35.0	24.6	36.0	17.3	31.0	15.6	33.0
H3	9.7	8.4	6.5	14.8	11.3	14.4	7.7	10.7	8.3	12.7
H4	5.9	6.3	6.4	9.3	8.6	13.4	7.0	9.7	7.5	10.4
Total	66.6	62.1	45.0	115.5	76.6	118.8	58.3	89.7	45.1	106.5
					NH_4-N					
H1	31.2	47.0	40.6	37.1	40.1	47.3	40.9	33.3	55.8	52.8
H2	19.5	48.0	47.5	43.1	26.3	53.7	43.5	33.7	42.8	52.8
H3	20.4	43.6	32.3	42.3	21.0	49.3	34.5	47.0	19.4	35.3
H4	14.9	18.2	22.8	42.5	12.8	51.4	26.8	43.6	14.1	21.3
Total	86.0	156.8	143.2	165.0	100.2	201.7	145.7	157.6	105.1	162.2

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 12: Field Experiment; contents of NO_3- & NH_4-N in soil (kg./ha.)
Sampling 5 (June 1969).

PLANTED

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	8.0	28.4	17.4	35.6	11.3	19.2	17.2	19.0	12.0	20.4
H2	6.5	26.4	10.7	37.9	7.5	12.6	6.1	16.8	8.8	13.5
H3	2.8	11.9	5.4	9.5	3.9	5.5	3.1	7.7	3.0	7.3
H4	1.8	9.6	3.5	4.8	3.0	3.6	2.1	4.0	1.9	7.1
Total	19.1	76.3	37.0	87.8	25.7	40.9	28.5	47.5	25.7	48.3
					NH_4-N					
H1	24.9	38.3	29.0	39.3	23.6	24.8	21.6	15.9	19.6	19.1
H2	25.2	38.3	23.0	29.1	31.4	16.6	23.1	17.2	24.2	14.2
H3	18.5	32.2	22.1	27.6	22.5	13.7	22.8	12.8	17.1	12.2
H4	11.3	21.4	13.5	24.4	19.4	10.4	8.1	9.7	6.8	6.6
Total	79.9	130.2	87.6	120.4	96.9	61.5	75.6	55.6	67.7	52.0

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 13 : Field Experiment; contents of NO_3- & NH_4-N in soil (kg./ha.)
Sampling 6 (July 1969).

PLANTED

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	4.6	5.6	6.4	4.8	4.4	5.0	4.0	5.8	3.4	5.4
H2	4.1	6.3	5.0	5.7	3.9	4.5	3.1	4.9	2.8	4.9
H3	2.4	3.3	2.1	2.5	2.8	3.5	1.8	3.8	1.5	1.7
H4	1.5	2.7	1.5	2.1	2.1	3.0	2.3	3.1	1.2	2.3
Total	12.6	17.9	14.8	15.1	13.2	16.0	11.2	17.6	8.9	14.3
					NH_4-N					
H1	25.8	20.1	2.9	23.1	23.2	24.8	16.2	35.3	16.1	33.8
H2	15.8	16.3	7.1	14.0	18.3	17.9	13.6	26.0	10.3	20.7
H3	8.2	3.1	4.3	10.9	11.5	14.4	8.7	16.5	5.9	13.6
H4	6.7	1.9	3.9	3.4	6.9	9.2	5.7	10.2	3.7	3.8
Total	56.5	41.4	18.2	51.4	59.9	62.3	44.2	88.0	36.0	71.9

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 14 : Field Experiment; contents of NO_3-N & NH_4-N in soil (kg./ha.).

Sampling 7 (Sept. 1969).

PLANTED

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					NO_3-N					
H1	23.6	19.4	17.3	22.2	25.9	17.2	20.2	13.9	23.6	19.3
H2	17.5	13.0	16.7	14.2	20.8	13.2	17.3	12.9	22.1	15.8
H3	8.9	6.0	5.7	7.1	7.0	5.9	8.2	5.5	7.7	6.2
H4	6.1	5.0	4.9	3.8	4.9	3.4	5.5	3.3	6.4	3.6
Total	56.1	43.4	44.6	47.3	58.6	39.7	51.2	35.6	59.8	44.9
					NH_4-N					
H1	49.1	60.1	44.8	37.0	58.7	14.9	55.4	8.2	29.8	45.6
H2	37.3	36.4	62.9	36.2	61.1	15.1	47.8	27.9	52.7	56.3
H3	27.0	22.9	23.2	22.1	33.2	22.4	29.9	8.4	16.1	35.0
H4	22.3	13.8	10.5	16.0	18.9	10.8	19.2	2.0	8.5	22.2
Total	135.7	133.2	141.4	111.3	171.9	63.2	152.3	46.5	107.1	159.2

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 15 : Field Experiment; contents of $(NO_3^- + NH_4)$-N in soil (kg./ha.).

Sampling 1 (Dec. 1968)

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
FALLOW										
H1	54.0		87.2		66.2		91.8		84.1	
H2	46.5		63.0		51.9		68.6		64.8	
H3	26.7		41.8		50.0		47.6		40.4	
H4	19.8		34.1		42.5		33.2		30.9	
Total	147.0		226.1		210.6		241.2		220.2	
PLANTED										
H1	51.8		65.9		87.2		79.3		78.5	
H2	44.7		56.8		61.9		51.4		47.1	
H3	29.8		40.0		30.0		31.4		17.8	
H4	26.4		35.6		17.1		20.1		10.7	
Total	152.7		203.3		196.2		182.2		154.1	

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 16 : Field Experiment; contents of (NO_3- + NH_4-)N in soil. (kg./ha.)

Sampling 2 (Jan. 1969)

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
FALLOW										
H1	96.4	98.1	95.8	82.6	97.6	97.9	89.8	100.2	70.5	94.8
H2	62.7	98.4	60.8	83.8	67.8	97.5	117.7	94.5	63.4	71.0
H3	38.6	62.2	42.9	61.9	45.3	76.9	75.0	67.7	49.0	50.2
H4	24.7	46,6	27.0	57.3	31.5	69.9	53.1	58.7	37.0	35.1
Total	222.4	304.3	226.4	285.6	242.2	342.2	335.6	321.1	219.9	251.1
PLANTED										
H1	91.7	99.0	90.0	86.4	103.5	89.0	108.1	81.6	79.4	112.1
H2	74.2	82.4	72.2	83.8	82.7	97.9	84.3	83.3	90.4	97.2
H3	47.1	56.8	39.9	64.2	59.3	53.8	52.2	52.3	41.2	67.1
H4	119.3	37.2	35.5	63.0	47.6	51.8	49.7	61.2	29.3	55.5
Total	272.3	275.4	237.6	297.4	293.1	271.4	294.3	278.4	230.3	332.9

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table17 : Field Exp&riment;contents of (NO_3- + NH_4-)N in soil.(kg./ha.).

Sampling 3 (Feb. 1969)

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
FALLOW										
H1	69.9	83.9	60.2	64.6	76.1	54.1	33.4	64.2	75.0	81.7
H2	75.9	75.2	78.8	74.1	86.0	58.8	34.9	60.0	113.6	83.1
H3	77.8	50.4	70.2	72.I	66.1	67.9	41.8	63.7	84.4	61.2
H4	65.7	48.4	55.7	71.6	47.4	69.7	46.7	52.5	61.0	51.5
Total	288.3	257.9	264.9	282.4	276.4	250.5	156.8	240.4	334.0	277.5
PLANTED										
H1	69.6	73.4	78.0	40.2	54.6	31.6	41.5	93.9	35.2	60.8
H2	68.2	88.8	80.5	47.5	59.1	31.4	77.1	99.1	55.2	76.9
H3	64.0	74.7	86.0	52.4	60.4	48.2	65.6	95.8	45.4	67.6
H4	77.4	70.3	81.9	67.1	52.6	45.0	32.8	108.0	33.6	59.6
Total	279.2	306.2	326.4	207.2	226.7	156.2	217.0	396.8	163.4	264.9

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table18 : Field Exp&riment;contents of (NO_3- + NH_4-)N in soil.(kg./ha.).

Sampling 4 (May 1969).

Horizon	O		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					FALLOW					
H1	54.5	106.4	54.9	113.8	74.4	121.9	50.6	98.9	45.2	93.5
H2	45.6	91.1	45.9	105.7	58.2	82.8	47.0	82.2	42.7	87.7
H3	32.7	55.9	37.8	58.1	27.5	49.3	39.1	59.8	36.5	49.8
H4	25.7	45.2	23.9	62.6	16.0	69.1	38.4	71.6	31.5	37.4
Total	158.5	298.6	162.5	340.2	176.1	322.7	175.1	312.5	155.9	268.3
					PLANTED					
H1	61.5	75.5	58.8	93.5	72.2	98.3	67.2	71.6	69.5	103.2
H2	40.2	66.9	61.4	78.1	50.9	89.7	60.8	64.7	58.4	85.8
H3	30.1	52.4	38.8	57.1	32.3	63.7	42.2	57.7	27.7	48.0
H4	20.8	24.5	29.2	51.8	21.4	64.8	33.8	53.3	21.5	31.7
Total	152.6	218.9	188.2	280.5	176.8	320.5	204.0	247.3	150.2	268.7

Notes; 1- i and ii are replicates

2- O = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 19: Field Experiment; contents of $(NO_3^- + NH_4^-)N$ in soil. (kg./ha.).
Sampling 5 (June 1969).

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
FALLOW										
H1	38.8	56.7	89.6	80.1	104.0	89.9	66.5	84.3	60.9	71.0
H2	35.5	61.8	42.0	56.0	69.1	60.2	23.8	55.4	28.2	49.9
H3	25.8	39.6	25.4	37.2	29.3	28.0	17.4	35.1	17.4	26.4
H4	12.6	39.6	17.3	28.7	14.1	22.6	13.8	30.5	14.8	17.4
Total	112.7	202.7	175.3	202.0	216.5	200.7	121.5	105.3	120.3	164.7
PLANTED										
H1	32.9	66.7	46.4	74.9	34.9	44.0	38.8	34.9	31.6	39.5
H2	31.7	64.7	33.7	67.0	39.1	29.2	29.2	34.0	33.0	27.7
H3	21.3	44.1	27.5	37.1	26.4	19.2	25.9	20.5	20.1	19.5
H4	13.1	31.0	17.0	29.2	22.4	14.0	10.2	13.7	8.7	13.6
Total	99.0	206.5	124.6	208.2	122.6	102.4	104.1	103.2	93.4	100.3

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 20 : Field Experiment; contents of (NO_3- + NH_4-)N in soil.(kg./ha.).

Sampling 6 (July 1969).

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
					FALLOW					
H1	25.7	28.7	34.0	54.9	90.3	76.0	34.8	48.2	44.8	88.4
H2	16.6	24.9	21.8	36.7	32.2	30.5	20.5	23.1	26.0	46.4
H3	10.0	12.7	11.5	12.3	12.3	19.5	11.1	18.6	14.1	25.9
H4	7.1	10.1	3.8	14.4	6.8	13.4	9.1	11.5	9.9	17.6
Total	59.4	76.3	71.1	128.3	121.6	149.4	75.5	101.4	94.8	178.3
					PLANTED					
H1	30.4	25.7	9.1	27.9	27.6	29.8	20.2	11.1	19.5	39.2
H2	19.9	22.6	12.1	19.7	22.2	22.4	16.7	30.9	13.1	25.6
H3	10.6	6.4	6.4	13.4	14.3	17.9	10.5	20.3	7.4	15.3
H4	8.2	4.6	5.4	5.5	9.0	12.2	8.0	13.3	4.9	6.1
Total	123.1	59.3	33.0	66.5	73.1	82.3	55.4	105.6	44.9	86.2

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 21 : Field Experiment; contents of $(NO_3^- + NH_4^-)N$ in soil.(kg./ha.).

Sampling 7 (Sept. 1969).

Horizon	0		A_1S_1		A_1S_2		A_2S_1		A_2S_2	
	i	ii	i	ii	i	ii	i	ii	i	ii
FALLOW										
H1	65.5	106.0	82.1	64.5	98.3	53.5	82.7	112.5	101.5	102.8
H2	42.6	73.6	60.5	55.3	97.3	59.2	65.5	82.0	67.7	65.7
H3	23.0	31.0	29.4	37.1	31.3	30.8	45.9	44.5	31.8	33.4
H4	14.7	21.8	12.5	19.5	16.2	9.9	23.3	32.4	32.8	19.8
Total	145.8	182.4	184.5	176.4	223.1	154.4	217.4	271.4	224.8	221.7
PLANTED										
H1	72.7	79.5	62.1	59.2	84.6	32.1	75.6	22.1	53.4	65.0
H2	54.8	49.4	89.6	50.4	81.9	28.3	65.1	40.8	74.8	72.1
H3	35.9	28.9	28.9	29.2	40.2	28.3	38.1	13.9	23.8	41.2
H4	28.4	18.8	15.4	19.8	23.8	14.2	24.7	5.3	14.9	25.8
Total	191.8	176.6	186.0	158.6	230.5	102.9	203.5	82.1	166.9	104.1

Notes; 1- i and ii are replicates

2- 0 = no N treatment ; A_1S_1 , A_1S_2 , A_2S_1 , and A_2S_2 = N treatments.

Table 22 : Field Experiment ; Weight of soil (> 2 mm.) and gravels (stones) in each 15 cm. core segment (45.59 cm^3) in grams.

0-15 cm		15-30cm		30-45 cm		45-60 cm	
soil	gravels	soil	gravels	soil	gravels	soil	gravels
533	90	516	116	523	191	427	210
538	81	576	109	412	197	293	240
545	78	525	105	401	156	342	191
562	89	546	115	440	147	441	264
536	91	515	114	600	110	370	205
443	83	534	100	501	105	362	187
475	76	546	121	396	201	430	175
534	78	554	103	401	161	298	215
611	83	517	98	383	182	498	231
500	90	555	101	398	132	520	198

Note: Values in each row denote one sample . Ten samples (at each depth) were taken at random from the field.

* Table 23 : Field Experiment , D.M. Yield of plant, %N in D.M. plant , and N Uptake.

A. Sampling 2 (Jan. 1969)

Treatment	Replicate	D.M. Yield kg/ha	% N	N Uptake kg/ha
0	i	29	4.29	1.25
	ii	27	4.85	1.29
A_1S_1	i	56	5.02	2.80
	ii	39	4.54	1.76
A_1S_2	i	45	4.20	2.33
	ii	37	4.86	1.78
A_2S_1	i	35	4.82	1.70
	ii	39	5.07	2.00
A_2S_2	i	30	4.96	1.48
	ii	47	4.67	2.19

B. Sampling 3 (Feb. 1969)

0	i	40	4.96	1.99
	ii	50	4.65	2.31
A_1S_1	i	51	4.73	2.41
	ii	50	4.72	2.38
A_1S_2	i	49	4.59	2.25
	ii	41	4.60	1.88
A_2S_1	i	37	4.77	1.79
	ii	48	4.43	2.14
A_2S_2	i	39	4.53	1.79
	ii	55	4.20	2.32

(Table 23 cont.)

C .Sampling 4 (May 1969)

Treatment.	Replicate	D.M. Yield. kg/ha	% N	N Uptake kg/ha
0	i	333	3.70	12.34
	ii	158	4.60	7.26
A_1S_1	i	185	4.54	8.39
	ii	323	3.52	11.37
A_1S_2	i	269	3.96	10.67
	ii	206	4.88	10.05
A_2S_1	i	320	3.62	11.58
	ii	374	4.18	15.65
A_2S_2	i	419	3.64	15.27
	ii	201	4.51	9.08

D. Sampling 5 (June 1969)

0	i	2039	1.27	26.00
	ii	1632	1.58	25.86
A_1S_1	i	3460	2.19	75.78
	ii	3637	1.73	62.92
A_1S_2	i	2801	2.10	58.82
	ii	3501	2.40	84.20
A_2S_1	i	5126	2.38	121.99
	ii	3127	1.89	59.26
A_2S_2	i	4827	1.99	96.05
	ii	4453	2.26	100.85

(Table 23 cont.)

E. Sampling 6 (July 1969)

Treatment.	Replicate.	D.M. Yield. kg/ha	% N	N Uptake. kg/ha
0	i	4113	0.87	35.99
	ii	3739	0.78	29.35
A_1S_1	i	5574	1.13	62.99
	ii	7070	1.16	82.36
A_1S_2	i	8497	1.18	100.70
	ii	8362	1.40	117.48
A_2S_1	i	9109	1.38	126.16
	ii	9789	1.15	112.57
A_2S_2	i	9041	1.25	113.47
	ii	8362	1.25	104.52

F. Sampling 7 (Sept. 1969)

0	i	4303	0.82	35.29
	ii	4283	0.90	38.76
A_1S_2	i	7872	1.08	85.41
	ii	10469	1.05	110.45
A_1S_2	i	10979	0.87	95.52
	ii	12223	1.13	138.73
A_2S_1	i	12644	1.08	136.56
	ii	11319	0.91	103.57
A_2S_2	i	13970	1.20	167.64
	ii	11421	1.20	137.05

* Sampling 1 (Dec. 1968) is not included ; at this time there was very little plant growth.

* Table 24 : Field Experiment. D.M. Yield and N Uptake at harvest.

Treatment		D.M. Yield Straw	Grain	Total	N Uptake Straw	Grain	Total
		tOns/ha			kg./ha		
A_1S_1	i	2.38	3.21	5.59	12.4	56.2	68.6
A_1S_1	ii	3.21	4.47	7.68	19.9	80.0	99.9
A_1S_2	i	2.66	3.91	6.57	13.8	71.6	85.4
A_1S_2	ii	2.66	3.91	6.57	16.5	81.0	97.5
A_2S_1	i	2.38	4.33	6.71	11.4	75.4	86.8
A_2S_1	ii	2.33	5.03	5.36	11.2	97.1	108.3
A_2S_2	i	2.36	4.05	6.41	15.0	81.0	76.0
A_2S_2	ii	3.08	3.35	6.43	13.2	67.8	81.0
no N	i	0.98	1.82	2.80	5.8	32.5	38.3
no N	ii	0.80	1.93	2.73	4.2	35.8	40.0

* i and ii denote replicates.

Unlike yields (during the season) in table 23 which were based on plants sampled per plot , yields in this table are from actual harvest of plots at the end of experiment.

Table 25 : Field experiment; Rainfall in the period Dec. 1968 to Sept. 1969, mm.

Date	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.
1	0	0	9.0	0.1	0	0	0.5	1.9	0.2	0
2	0	0	0	0	0	9.5	7.8	0	10.2	0
3	0	0	0	0	0	0.1	0.3	0.6	3.0	0
4	4.4	1.3	0	0	0	4.2	0	0	0.1	0
5	4.5	1.0	5.0	0	0	0.1	0	0	0.1	1.6
6	0.2	3.7	0.3	0	0	16.0	0	0.2	0	0
7	0	7.6	0	0	0	9.8	0	8.7	0	0
8	0	0.3	0	0	0	6.9	0	0.2	7.5	0
9	0	0	0	0	2.2	0.1	0	2.1	10.0	0.2
10	0.4	1.2	5.9	1.7	0.3	4.1	0	0	0	18.2
11	1.3	0.2	0.5	0	7.2	2.8	0	0	0.7	6.3
12	0	16.6	0.4	0.4	0	9.7	0	0	0	0
13	0	0.8	0	3.7	0.1	4.1	0.5	0	0.5	0.1
14	0.1	1.9	5.2	2.2	2.3	1.0	0	0	0	0
15	0	0	0	0.2	0.4	8.9	0.7	0.2	0	0
16	3.6	0.5	0	0.3	0	0.4	10.2	0	0.1	3.9
17	7.9	2.9	0	3.7	0	2.0	1.0	1.1	0	0
18	2.5	6.6	0.5	1.7	0	2.4	2.2	0.7	0	0
19	0.3	0.1	0	2.3	0	0	7.2	0	0.5	0
20	3.9	13.3	4.6	0.9	0.2	0	5.0	0.2	15.4	0.8
21	0.1	8.2	0.3	0	11.0	0	5.7	0	3.3	3.2
22	8.9	0	15.7	0	6.8	0	1.0	4.5	2.0	0
23	0	0.2	0	0	2.6	0	8.0	1.2	0	0
24	0	0.5	0.2	0.8	1.5	7.5	0	0	0	0.4
25	1.8	0	1.9	0	0.6	0.3	0.5	0	1.4	0.4
26	0	0	0.3	0	0	10.7	1.4	12.9	0.2	2.4
27	0	0.5	0.9	0	0	3.8	0	0	0	0
28	0.3	0	1.8	1.1	1.7	3.3	1.8	1.6	0	1.1
29	0.6	0.8	-	0.3	0.1	0	0	0	0	0.2
30	0.1	3.7	-	0.3	0	0.4	0.3	0	0	0
31	0	0	-	0.3	-	4.9	-	0	0	-

Table 26: Greenhouse Experiment I ; Statistical analysis of data.

A. N Uptake

	d.f.			d.f.			d.f.	
B	1	*	LR	2	ns.	ALR	4	ns.
A	2	*	NR	2	ns.	ANR	4	ns
Error(1)	2		LNR	2	ns	ALNR	4	ns
L	1	***	AL	2	ns	Error(2)	33	ns
N	1	***	AN	2	ns			
LN	1	***	ALN	2	ns			
R	2	***	AR	4	*	Total	71	

B. Mineral N in soil
(i.e. NO_3- & NH_4- N)

	d.f.	NO_3-N	NH_4-N	min.N		d.f.	NO_3-N	NH_4-N	min. N
B	1	ns	ns	ns	LNPR	2	ns	ns	ns
A	2	ns	ns	ns	AL	2	ns	ns	ns
Error (1)	2				AN	2	ns	ns	ns
L	1	*	ns	*	ALN	2	ns	ns	ns
N	1	***	ns	***	AP	2	***	ns	***
LN	1	ns	ns	ns	ALP	2	ns	ns	ns
P	1	***	ns	***	ANP	2	ns	ns	ns
LP	1	***	ns	***	ALNP	2	ns	ns	ns
NP	1	*	ns	*	AR	4	**	ns	**
LNP	1	ns	ns	ns	ALR	4	ns	ns	ns
R	2	***	ns	***	ANR	4	ns	ns	ns
LR	2	ns	ns	ns	ALNR	4	ns	ns	ns
NR	2	*	ns	*	APR	4	***	ns	***
LNR	2	ns	ns	ns	ALPR	4	ns	ns	ns
PR	2	***	ns	***	ANPR	4	ns	ns	ns
LPR	2	**	ns	**	ALNPR	4	ns	ns	ns
NPR	2	ns	ns	ns	Error (2)	69			

(cont.)

(Table 26 B. Mineral N in soil ; cont.)

	d.f.	NO_3- N	NH_4- N	min. N
HL	1	***	*	***
HQ	1	***	ns	***
AH	4	***	ns	***
LH	2	ns	ns	ns
NH	2	***	ns	***
PH	2	*	ns	*
RH	4	***	ns	***
LNH	2	*	ns	*
LPH	2	ns	ns	*
NPH	2	***	ns	***
LNPH	2	**	ns	**
LRH	4	ns	ns	ns
NRH	4	***	ns	***
LNRH	4	ns	ns	ns
PRH	4	ns	ns	ns
LPRH	4	ns	ns	ns
NPRH	4	***	ns	**
LNPRH	4	ns	ns	ns
ALH	4	ns	ns	ns
ANH	4	ns	ns	ns
ALNH	4	ns	ns	ns
APH	4	**	ns	**
ALPH	4	**	ns	**
ANPH	4	*	ns	**
ALNPH	4	ns	ns	ns
ARH	8	**	ns	**
ALRH	8	ns	ns	ns
ANRH	8	***	ns	***
ALNRH	8	ns	ns	ns
APRH	8	*	ns	ns
ALPRH	8	ns	ns	ns
ANPRH	8	*	ns	*
ALNPRH	8	ns	ns	ns
Error (3)	144			
Total	431			

C: Leaching losses of mineral N (at one level of watering - viz. R_3)

	d.f.			
B	1	ns	ns	ns
A	2	ns	ns	ns
Error (1)	2			
L	1	ns	ns	ns
N	1	***	ns	***
LN	1	ns	ns	ns
P	1	***	ns	***
LP	1	**	ns	**
NP	1	ns	ns	ns
LNP	1	ns	ns	ns
AL	2	ns	ns	ns
AN	2	ns	ns	ns
ALN	2	ns	ns	ns
AP	2	ns	ns	ns
ALP	2	ns	ns	
ANP	2	ns	ns	ns
ALNP	2	ns	ns	ns
Error (2)	21			
TOTAL	47			

Table 26 D: Sum of (mineral N in soil + NUptake + leaching loss of mineral N)

	d.f.			d.f.			d.f.	
B	1	ns	LR	2	ns	ANP	2	ns
A	2	ns	NR	2	ns	ALNP	2	ns
Error (1)	2		LNR	2	ns	AR	4	*
L	1	***	PR	2	ns	ALR	4	ns
N	1	***	LPR	2	ns	ANR	4	ns
LN	1	ns	NPR	2	ns	ALNR	4	ns
P	1	*	LNPR	2	ns	APR	4	ns
LP	1	ns	AL	2	ns	ALPR	4	ns
NP	1	ns	AN	2	ns	ANPR	4	ns
LNP	1	ns	ALN	2	ns	ALNPR	4	ns
R	2	***	AP	2	ns	Error (2)	69	
			ALP	2	ns	Total	143	

Ø : Effects are due to :-

B: Block.

A: Sampling date .

L: Soil.

N: Nitrogen rate.

P: Soil/Plant system .

R: Water régime.

H: Soil horizon .

Q: Quadratic effect .

and

ns : Effect is statistically not significant.

* : " " " significant at 5% level of probability.

** : " " " " 1% " " " .

***: " " " " 0.1% " " " .

d.f. : Degrees of freedom .

Table 27 : Greenhouse Experiment I ; contents of NO_3-N in soil (kg./ha)

Sampling 1 (3rd. week of experiment)

Water régime	Horizon	Fallow				Planted			
		no N		N		no N		N	
		* i	*ii	i	ii	i	ii	i	ii
Topsoil									
R_1	H1	8.1	36.1	53.9	56.0	6.6	14.4	23.1	14.3
	H2	16.5	40.0	45.5	40.8	15.3	16.9	35.8	13.8
	H3	29.6	44.1	62.6	39.3	42.0	35.3	40.7	31.7
	Total	54.2	120.2	162.0	136.1	63.9	66.6	99.6	59.8
R_2	H1	2.5	25.8	57.7	69.4	4.4	10.9	16.5	18.4
	H2	12.7	39.4	44.4	45.6	13.3	34.2	22.3	18.2
	H3	41.3	51.8	55.3	51.3	38.8	38.0	46.6	34.7
	Total	56.5	117.0	157.4	166.3	56.5	83.1	85.4	71.3
R_3	H1	7.3	17.0	10.9	14.5	7.4	15.8	13.5	16.3
	H2	8.8	18.8	15.9	18.9	6.8	17.8	15.7	18.1
	H3	17.5	21.9	27.7	31.6	14.9	17.6	40.6	22.0
	Total	33.6	57.7	54.5	65.0	29.1	51.2	69.8	56.4
Subsoil									
R_1	H1	30.4	29.2	36.7	44.8	51.1	47.1	42.5	27.7
	H2	35.3	35.2	40.4	43.8	45.6	20.8	29.7	24.0
	H3	36.4	34.6	41.2	43.0	50.7	34.1	30.1	25.7
	Total	102.1	99.0	118.3	131.6	147.4	102.0	102.3	77.4
R_2	H1	14.2	18.8	35.0	44.1	7.3	16.1	26.6	34.2
	H2	24.7	27.2	35.1	39.0	11.4	28.9	20.6	32.1
	H3	42.2	47.1	35.5	51.7	30.8	34.5	28.7	37.8
	Total	81.1	93.1	105.6	134.8	49.5	79.5	65.9	104.1
R_3	H1	5.6	16.5	6.2	15.9	3.7	14.9	10.0	13.6
	H2	6.7	18.8	12.1	17.3	4.4	16.4	12.6	17.3
	H3	5.1	25.1	44.4	24.3	5.5	17.7	16.3	30.2
	Total	17.4	60.4	62.7	57.5	13.6	49.0	38.9	61.1

* i and ii denote replicates

Table 28 : Greenhouse Experiment I ; contents of NO_3-N in soil (kg./ha.)

Sampling 2 (5th. week of experiment)

Water régime	Horizon	Fallow				Planted			
		no N		N		no N		N	
		* i	*ii	i	ii	i	ii	i	ii
Topsoil									
R_1	H1	15.9	30.0	51.8	61.3	6.3	8.6	7.5	23.3
	H2	24.8	46.2	25.2	63.7	6.6	10.3	9.2	21.1
	H3	36.0	55.3	31.3	44.8	10.9	11.5	16.1	32.7
	Total	76.7	131.5	108.3	169.8	23.8	30.4	32.8	78.1
R_2	H1	10.6	27.9	13.9	20.9	9.9	9.7	7.1	15.2
	H2	15.2	39.4	19.9	30.3	11.0	9.1	7.1	15.1
	H3	19.7	41.1	31.4	55.2	15.7	11.6	12.9	18.4
	Total	45.5	108.4	55.2	116.4	36.6	30.4	27.1	48.7
R_3	H1	7.7	15.4	9.6	14.4	6.5	10.6	6.6	15.2
	H2	17.1	12.8	10.6	13.2	7.7	8.1	7.1	15.4
	H3	11.3	14.3	13.7	17.7	7.8	9.6	7.3	16.1
	Total	36.1	42.5	33.9	45.3	22.0	28.3	21.0	36.7
Subsoil									
R_1	H1	12.1	18.3	25.8	42.4	7.0	12.8	13.1	34.5
	H2	18.4	27.4	22.5	37.2	8.3	19.4	11.5	32.8
	H3	21.4	36.4	20.2	31.2	13.1	22.1	14.5	21.6
	Total	51.9	82.1	68.5	110.8	28.4	54.3	39.1	88.9
R_2	H1	8.4	13.2	10.9	32.7	7.9	10.3	6.5	36.3
	H2	9.8	17.0	16.6	46.2	7.3	11.5	12.4	34.5
	H3	10.9	23.1	20.7	64.2	12.6	22.1	19.4	37.6
	Total	29.1	53.3	48.2	143.1	27.8	43.9	38.3	108.5
R_3	H1	7.7	10.3	8.4	11.2	6.8	13.3	7.7	9.2
	H2	7.9	11.1	7.8	12.3	7.2	17.0	7.7	7.0
	H3	8.0	11.2	7.8	14.7	9.0	19.0	8.2	9.3
	Total	23.6	32.6	24.0	38.2	23.0	49.3	23.6	25.5

* i and ii denote replicates

Table 29 : Greenhouse Experiment I ; contents of NO_3-N in soil

(kg./ha.)

Sampling 3 (7th. week of experiment)

Water régime	Horizon	Fallow				Planted			
		no N		N		no N		N	
		* i	*ii	i	ii	i	ii	i	ii
Topsoil									
R_1	H1	36.8	35.9	78.3	70.0	8.0	13.6	9.1	8.1
	H2	64.7	50.7	56.0	50.4	12.8	11.3	10.8	10.0
	H3	89.4	94.6	81.7	52.0	16.0	12.7	24.8	10.6
	Total	190.9	181.2	216.0	172.4	36.8	37.6	44.7	28.7
R_2	H1	14.2	10.8	28.0	44.6	8.2	7.3	13.2	10.3
	H2	27.0	22.3	50.0	19.6	7.5	9.3	12.6	7.5
	H3	43.1	47.0	62.5	16.9	10.8	8.5	19.9	8.6
	Total	84.3	80.1	141.1	81.1	26.5	25.1	45.7	26.4
R_3	H1	10.4	10.3	12.7	12.4	9.5	10.5	7.5	11.0
	H2	12.0	11.1	15.7	10.7	11.2	9.8	11.1	12.0
	H3	11.7	15.8	12.7	12.2	9.1	10.2	11.4	10.6
	Total	34.1	37.2	40.1	35.3	29.8	30.5	30.0	33.6
Subsoil									
R_1	H1	26.9	13.7	47.9	33.9	8.8	8.1	16.1	43.3
	H2	40.8	37.6	45.0	46.1	9.9	6.8	9.1	22.3
	H3	48.0	56.3	46.2	48.6	13.6	9.9	14.3	64.6
	Total	115.7	107.6	139.1	128.6	31.3	24.8	39.5	130.2
R_2	H1	10.8	14.0	14.9	14.2	10.7	9.1	6.5	7.2
	H2	14.9	17.5	26.8	24.9	8.8	11.2	8.7	8.4
	H3	22.0	30.2	37.1	40.4	9.0	12.9	17.8	24.9
	Total	47.7	61.7	80.8	79.5	28.5	33.2	33.0	40.5
R_3	H1	8.8	12.0	10.5	14.5	8,4	11.9	11.8	8.1
	H2	10.1	10.7	10.5	12.8	10.7	9.7	9.5	9.7
	H3	13.0	11.1	10.9	13.2	10.8	11.5	8.9	9.8
	Total	31.9	33.8	31.9	40.5	19.9	33.1	30.2	26.6

* i and ii denote replicates

Table 30 : Greenhouse Experiment I ; contents of NH_4-N in soil (kg./ha.)

Sampling 1 (3rd. week of experiment)

Water régime	Horizon	Fallow				Planted			
		no N		N		no N		N	
		* i	*ii	i	ii	i	ii	i	ii
Topsoil									
R_1	H1	2.6	2.7	0.8	5.6	4.0	0.4	0.8	3.3
	H2	1.4	1.9	0.5	4.3	3.1	1.7	1.7	5.3
	H3	1.4	2.4	0.5	6.1	1.3	1.9	2.8	2.3
	Total	5.4	7.0	1.8	16.0	8.4	4.0	5.3	10.8
R_2	H1	3.8	2.6	3.8	6.8	1.8	0.7	3.7	4.1
	H2	2.5	2.5	2.9	5.8	5.2	0.9	2.2	3.7
	H3	1.9	0.5	2.0	6.3	1.8	5.9	0.8	6.1
	Total	8.2	5.6	8.7	18.9	8.8	7.5	6.7	13.9
R_3	H1	2.9	3.2	3.6	1.2	4.2	1.9	0.4	1.8
	H2	1.9	2.9	4.5	0.7	5.4	1.5	1.9	2.0
	H3	1.0	4.4	3.6	3.1	2.8	2.4	3.5	1.0
	Total	5.8	10.5	11.7	5.0	12.4	5.8	5.8	4.8
Subsoil									
R_1	H1	3.2	4.9	4.8	2.4	1.9	5.3	1.8	6.9
	H2	3.4	4.0	3.0	1.9	4.0	3.9	3.2	4.0
	H3	2.7	4.4	5.7	1.0	3.4	4.6	1.4	3.5
	Total	9.3	13.3	13.5	5.3	10.3	13.8	6.4	14.4
R_2	H1	1.8	2.8	1.4	5.0	2.7	2.0	2.8	1.8
	H2	1.4	2.4	2.2	5.4	1.4	2.2	2.8	1.7
	H3	2.6	3.1	2.5	5.3	0.4	3.0	2.7	0.9
	Total	5.8	8.3	6.1	15.7	4.5	7.2	8.3	4.4
R_3	H1	4.0	5.6	0.9	5.0	1.1	6.1	3.5	0.4
	H2	1.6	3.3	1.9	4.4	2.5	6.5	4.4	1.0
	H3	1.5	4.5	1.0	5.6	5.0	7.1	4.7	4.7
	Total	7.1	13.4	3.8	15.0	8.6	19.7	12.6	6.1

* i and iidenote replicates

Table 31 : Greenhouse Experiment I ; contents of NH_4-N in soil (kg./ha.)

Sampling 2 (5th. week of experiment)

Topsoil

Water régime	Horizon	Fallow no N * i	Fallow no N *ii	Fallow N i	Fallow N ii	Planted no N i	Planted no N ii	Planted N i	Planted N ii
R_1	H1	5.9	2.3	3.7	2.8	4.6	2.7	4.3	6.7
	H2	6.4	2.9	3.5	4.4	3.5	4.7	2.1	6.3
	H3	6.2	1.6	6.5	4.3	2.2	4.9	5.5	6.1
	Total	18.5	6.8	13.7	11.5	10.3	12.3	11.9	19.1
R_2	H1	6.0	2.3	5.6	1.4	1.9	6.2	5.0	2.6
	H2	5.4	2.0	6.2	1.9	4.9	3.6	5.2	0.9
	H3	6.9	2.9	4.3	4.0	7.8	6.2	4.9	2.8
	Total	18.7	7.2	16.1	7.3	14.2	16.0	15.1	6.3
R_3	H1	5.4	3.4	5.5	4.3	7.0	5.8	4.8	1.8
	H2	6.3	4.1	3.4	3.3	6.8	5.7	7.6	0.5
	H3	8.1	8.1	5.7	5.7	6.8	4.4	8.8	1.9
	Total	19.8	15.6	14.6	13.3	20.6	15.9	21.2	4.2

Subsoil

R_1	H1	1.9	2.7	8.9	3.9	4.1	2.2	5.2	5.0
	H2	5.0	4.4	7.2	4.0	5.5	3.9	4.0	2.8
	H3	2.4	4.8	7.6	5.5	5.4	0.5	3.9	2.9
	Total	9.3	11.9	23.7	13.4	15.0	6.6	13.1	10.7
R_2	H1	4.2	6.6	5.2	0.9	5.4	2.8	5.7	2.3
	H2	4.4	4.0	2.4	0.5	6.8	3.4	6.4	1.9
	H3	8.3	5.8	4.9	7.6	4.4	3.7	5.9	1.5
	Total	16.9	16.4	12.5	9.0	16.6	9.9	18.0	5.7
R_3	H1	2.7	4.3	0.9	4.2	4.5	1.7	5.9	6.9
	H2	3.4	4.6	5.8	3.1	5.3	2.1	5.4	7.5
	H3	2.7	2.5	3.1	2.9	6.2	2.8	8.2	5.1
	Total	8.8	11.4	9.8	10.2	16.0	6.6	19.5	19.5

* i and ii denote replicates

Table 32 : Greenhouse Experiment I ; contents of NH_4-N in soil.

(kg./ha.)

Sampling 3 (7th. week of experiment)

Water régime	Horizon	Fallow				Planted			
		no N		N		no N		N	
		* i	*ii	i	ii	i	ii	i	ii
		Topsoil							
R_1	H1	3.6	1.3	4.2	2.1	3.2	0.8	1.9	0.7
	H2	2.4	1.4	4.2	0.4	3.0	1.7	2.1	1.7
	H3	4.0	1.0	1.9	0.5	1.2	1.2	1.7	1.3
	Total	10.0	3.7	10.3	3.0	7.4	3.7	5.7	3.7
R_2	H1	2.2	1.4	4.4	1.4	1.5	1.6	2.4	1.6
	H2	4.3	1.9	2.0	2.4	3.8	1.7	3.9	0.8
	H3	4.6	1.6	1.9	1.5	3.7	2.1	4.4	0.4
	Total	11.1	4.9	8.3	5.3	9.0	5.4	10.7	2.8
R_3	H1	0.9	0.4	1.3	1.3	1.4	1.3	1.3	0.4
	H2	2.0	0.5	1.4	0.5	2.5	2.4	2.5	1.0
	H3	2.7	0.5	2.1	1.5	1.8	2.0	2.6	1.1
	Total	5.6	1.4	4.8	3.3	5.7	5.7	6.4	2.5
		Subsoil							
R_1	H1	2.7	0.4	2.8	2.1	1.3	0.7	2.0	1.2
	H2	2.0	0.5	3.5	0.5	1.4	1.3	2.5	0.9
	H3	3.3	1.5	3.7	1.5	2.1	1.4	2.2	1.5
	Total	8.0	2.4	10.0	4.1	4.8	3.4	6.7	3.6
R_2	H1	1.4	1.4	4.6	0.4	1.9	1.7	2.4	1.2
	H2	2.0	1.5	3.5	1.5	2.0	4.1	2.2	0.4
	H3	1.0	1.5	1.9	1.5	1.6	4.5	2.7	0.9
	Total	4.4	4.4	10.0	3.4	5.5	10.3	7.3	2.5
R_3	H1	3.0	1.8	1.4	0.4	2.3	1.4	1.8	0.5
	H2	4.5	3.4	2.4	1.0	1.9	1.9	0.5	1.4
	H3	4.5	2.5	2.5	0.5	3.4	1.0	2.5	1.0
	Total	12.9	7.7	6.3	1.9	7.6	2.9	5.4	2.9

* i and ii denote replicates

Table 33 : Greenhouse Experiment I ; contents of (NO_3+ NH_4)N in soil (kg./ha.)

Sampling 1 (3rd. week of experiment)

Water régime	Horizon	Fallow				Planted			
		no N		N		no N		N	
		* i	*ii	i	ii	i	ii	i	ii
Topsoil									
R_1	H1	10.7	38.8	54.7	61.6	10.6	14.8	23.9	17.5
	H2	17.9	41.9	45.0	45.1	18.4	18.6	37.5	19.1
	H3	31.0	46.5	63.1	45.4	43.3	37.2	43,5	34.0
	Total	59.6	127.2	162.8	152.1	72.3	70.6	104.9	70.6
R_2	H1	6.3	28.4	61.5	76.2	6.2	11.6	20.2	22.5
	H2	15.2	42.9	47.3	51.4	18.5	35.1	24.5	21.9
	H3	43.2	52.3	57.3	57.6	40.6	44.9	47.4	40.8
	Total	64.7	123.6	166.1	185.2	65.3	91.6	92.1	85.2
R_3	H1	10.2	20.2	14.5	15.7	11.6	17.7	13.9	18.1
	H2	10.7	21.7	20.4	19.6	12.2	19.3	17.6	20.1
	H3	17.6	26.3	31.3	34.7	17.7	20.0	44.1	23.0
	Total	38.4	68.2	66.2	70.0	41.5	57.0	75.6	61.2
Subsoil									
R_1	H1	33.6	34.1	41.5	47.2	53.0	52.4	44.3	34.5
	H2	38.7	39.2	43.4	45.7	49.6	24.7	32.9	28.0
	H3	29.1	39.0	46.9	44.0	54.1	38.7	31.5	29.2
	Total	101.4	112.3	131.8	136.9	156.7	115.8	108.7	91.7
R_2	H1	16.0	21.6	36.4	49.1	10.0	18.1	29.4	36.0
	H2	26.1	29.6	37.3	44.4	12.8	31.1	23.4	33.8
	H3	44.8	50.2	38.0	57.0	31.2	37.5	31.4	38.7
	Total	86.9	101.4	111.7	150.5	54.0	86.7	84.2	108.5
R_3	H1	11.6	22.1	7.1	20.9	4.8	21.0	13.5	14.0
	H2	8.3	22.1	14.0	21.7	6.9	22.9	17.0	18.3
	H3	6.6	29.6	45.4	29.9	10.5	24.8	21.0	34.9
	Total	26.5	73.9	66.5	72.5	22.2	68.7	51.5	67.2

* i and ii denote replicates

Table 34 : Greenhouse Experiment I ; contents of (NH_4+ NO_3)N in soil. (kg./ha.)

Sampling 2 (5th. week of experiment)

Water régime	Horizon	Fallow				Planted			
		no N		N		no N		N	
		* i	*ii	i	ii	i	ii	i	ii
Topsoil									
R_1	H1	21.8	32.6	55.5	64.1	10.9	11.3	11.8	30.0
	H2	31.2	49.1	28.7	68.1	10.1	15.0	11.3	27.4
	H3	42.2	56.9	37.8	49.1	13.1	16.4	21.6	38.8
	Total	95.3	138.6	122.0	181.3	34.1	42.7	44.7	96.2
R_2	H1	16.6	30.2	19.5	22.3	11.8	15.9	12.1	17.8
	H2	20.6	41.4	26.1	32.2	15.9	12.7	12.3	16.0
	H3	26.6	44.0	35.7	59.2	23.5	17.8	17.8	21.2
	Total	63.8	115.6	81.3	113.7	51.2	46.4	42.2	55.0
R_3	H1	13.1	18.8	15.1	18.7	13.5	16.4	11.4	17.0
	H2	23.4	16.9	14.0	16.5	14.5	13.8	14.7	15.9
	H3	19.4	22.4	19.4	23.4	14.6	14.0	16.1	18.0
	Total	55.9	58.1	48.5	58.6	42.6	44.2	42.2	50.9
Subsoil									
R_1	H1	14.0	21.0	34.7	46.3	11.1	15.0	18.3	39.5
	H2	23.4	31.8	29.7	41.2	13.8	23.3	15.5	35.6
	H3	23.8	41.2	27.8	36.7	18.5	22.6	18.4	24.5
	Total	61.2	94.0	92.2	124.2	43.4	60.9	52.2	104.6
R_2	H1	12.6	19.8	16.1	33.6	13.3	13.1	12.2	38.6
	H2	14.2	21.0	19.0	46.7	14.1	15.9	18.8	36.4
	H3	19.2	28.9	25.6	71.8	17.0	25.8	25.3	39.1
	Total	46.0	69.7	60.7	152.1	44.4	54.8	56.3	114.1
R_3	H1	10.4	14.6	9.3	15.4	11.3	15.0	13.6	16.1
	H2	11.3	15.7	13.6	15.4	12.5	19.1	13.1	14.5
	H3	10.7	13.7	10.9	17.6	15.2	21.8	16.4	14.4
	Total	32.4	44.0	33.8	48.4	39.0	55.9	43.1	45.0

* i and ii denote replicates

Table35 : Greenhouse Experiment I ; contents of $(NO_3 + NH_4)N$ in soil (kg./ha.)

Sampling 3 (7th. week of experiment)

Water régime	Horizon	Fallow				Planted			
		no N		N		no N		N	
		* i	*ii	i	ii	i	ii	i	ii
Topsoil									
R_1	H1	40.4	37.2	82.5	72.1	11.2	16.8	11.0	8.8
	H2	67.1	52.1	60.2	50.8	15.8	13.0	12.9	11.7
	H3	93.4	95.6	83.6	52.5	17.2	13.9	26.5	11.9
	Total	200.9	184.9	226.3	175.4	44.2	43.7	50.4	32.4
R_2	H1	16.4	12.2	33.0	46.0	9.7	8.9	15.6	11.9
	H2	31.3	24.2	52.0	22.0	11.3	11.0	16.5	8.3
	H3	47.7	48.6	64.4	18.4	14.5	10.6	24.3	9.0
	Total	95.4	85.0	149.4	86.4	35.5	30.5	56.4	29.2
R_3	H1	11.3	10.7	14.0	13.7	10.9	11.8	8.8	11.4
	H2	14.0	11.6	17.1	11.2	13.7	12.2	13.6	13.0
	H3	14.4	16.3	14.8	14.7	10.9	12.2	14.0	11.7
	Total	39.7	38.6	45.9	39.6	35.5	36.2	36.4	36.1
Subsoil									
R_1	H1	29.6	14.1	50.7	36.0	10.1	8.8	18.1	44.5
	H2	42.8	38.1	48.5	46.6	11.3	8.1	11.6	23.2
	H3	51.3	57.8	49.9	50.1	15.7	11.3	16.5	66.1
	Total	123.7	110.0	149.1	132.7	37.1	28.2	46.0	133.8
R_2	H1	12.2	15.4	19.5	14.6	12.6	10.8	8.9	8.4
	H2	16.9	19.0	30.3	26.4	10.8	15.3	10.9	8.8
	H3	23.0	31.7	39.0	41.9	10.6	17.4	20.5	25.8
	Total	52.1	66.1	88.8	82.9	34.0	43.5	40.3	43.0
R_3	H1	12.7	13.8	11.9	14.9	10.7	13.3	13.6	8.6
	H2	14.6	12.1	12.9	13.8	12.6	10.2	10.6	11.1
	H3	17.5	13.6	13.4	13.7	14.2	12.5	11.4	10.8
	Total	44.8	38.2	38.2	42.4	37.5	36.0	35.6	30.5

* i and ii denote replicates

Table 36: Greenhouse Experiment I : N Uptake by plant (kg./ha.)

Water régime	TOPSOIL				SUBSOIL			
	no N		N		no N		N	
	i	ii	i	ii	i	ii	i	ii
Sampling 1 (3rd week of experiment)								
R_1	69.8	48.3	136.0	68.7	39.1	32.5	36.9	43.9
R_2	67.4	46.1	112.2	87.4	39.1	24.5	33.3	30.0
R_3	84.8	22.7	109.7	65.4	27.8	24.9	35.8	18.3
Sampling 2 (5th. week of experiment)								
R_1	97.3	81.2	135.6	89.2	61.4	46.4	54.5	49.4
R_2	88.1	99.5	137.5	102.0	49.7	33.3	47.5	48.3
R_3	79.7	52.7	114.4	77.1	23.8	19.7	40.2	43.5
Sampling 3 (7th. week of experiment)								
R_1	108.6	92.5	150.6	113.3	71.7	70.2	91.0	56.7
R_2	96.5	87.4	164.2	100.2	45.3	41.7	70.2	65.1
R_3	86.3	43.5	83.7	48.3	34.4	31.1	30.7	36.9

i & ii denote replicates.

Table 37 : Greenhouse Experiment I ; contents of mineral N lost by Leaching from soil columns (kg./ha.)

Sampling 1 (3rd week of experiment).

form of mineral N	FALLOW				PLANTED			
	no N		N		no N		N	
	* i	ii	i	ii	i	ii	i	ii
Topsoil								
NO_3-N	148.4	59.6	167.1	131.3	44.2	45.0	70.6	57.0
NH_4-N	1.1	0.7	1.1	1.5	2.6	1.1	2.2	0.4
(NO_3+ NH_4)N	149.5	60.3	168.2	132.8	46.8	46.1	72.8	57.4
Subsoil								
NO_3-N	84.8	68.7	150.3	127.2	58.5	59.2	93.6	96.5
NH_4-N	0.4	1.1	0.7	0.7	1.1	0.7	0.7	1.1
(NO_3+NH_4)N	85.2	69.8	151.0	127.9	59.6	59.9	94.3	97.6

* i and ii denote replicates.

Table 38 : Greenhouse Experiment I ; contents of mineral N lost by leaching from soil columns (kg./ha.)

Sampling 2 (5th. week of experiment)

form of mineral N	FALLOW				PLANTED			
	no N		N		no N		N	
	* i	ii	i	ii	i	ii	i	ii
Topsoil								
NO_3-N	146.6	142.2	217.9	154.3	68.4	65.4	85.2	87.4
NH_4-N	1.1	1.1	0.7	1.1	1.5	0.7	0.4	0.7
$(NO_3+NH_4)N$	147.7	143.3	218.6	155.4	69.5	66.1	85.6	88.1
Subsoil								
NO_3-N	113.0	136.4	163.4	149.9	76.4	119.6	114.1	111.5
NH_4-N	1.1	1.8	1.5	1.5	1.1	7.3	0.7	0.7
$(NO_3+NH_4)N$	114.1	138.2	164.9	151.4	77.5	126.9	114.8	112.2

* i and ii denote replicates.

Table 39 : Greenhouse Experiment I ; contents of mineral N lost by leaching from soil columns (kg./ha.)

Sampling 3 (7th. week of experiment)

form of mineral N	FALLOW				PLANTED			
	no N		N		no N		N	
	* i	ii	i	ii	i	ii	i	ii
Topsoil								
NO_3-N	152.5	149.5	213.9	187.9	80.8	66.6	110.8	132.7
NH_4-N	1.1	9.1	1.8	1.1	0.7	0.7	0.7	1.1
(NO_3+NH_4)N	153.6	158.6	215.7	189.0	81.5	67.2	111.5	133.8
Subsoil								
NO_3-N	119.2	111.5	167.5	175.9	63.3	43.5	105.7	115.5
NH_4-N	1.8	1.1	0.7	1.1	0.7	4.4	1.1	0.7
(NO_3+NH_4)N	121.0	112.6	168.2	177.0	64.0	47.9	106.8	116.2

* i and ii denote replicates.

Table 40 : Greenhouse Experiment I ; Sum of (a.N Uptake + b. mineral N lost by leaching + c. mineral N in Soil).

Sampling 1 (3rd week of experiment).

water régime	FALLOW				PLANTED			
	no N		N		no N		N	
	* i	ii	i	ii	i	ii	i	ii
	Topsoil							
R_1	59.6	127.2	162.8	152.1	142.1	118.9	240.9	139.3
R_2	64.7	123.6	166.1	185.2	132.7	137.7	204.3	172.6
R_3	187.9	128.5	234.4	202.8	173.1	125.8	258.1	184.0
	Subsoil							
R_1	101.4	112.3	131.8	136.9	195.8	148.3	145.6	135.6
R_2	86.9	101.4	111.7	150.5	93.1	111.2	117.5	138.5
R_3	111.7	143.6	217.5	200.4	109.6	163.5	181.6	183.1

* i and ii denote replicates.

Table 41 : Greenhouse Experiment I ; Sum of (a.N Uptake + B. mineral N lost by leaching + c. mineral N in soil).
Sampling 2 (5th. week of experiment).

water régime	FALLOW				PLANTED			
	no N		N		no N		N	
	* i	ii	i	ii	i	ii	i	ii
Topsoil								
R_1	95.3	138.6	122.0	181.3	131.4	123.9	180.3	185.4
R_2	63.8	115.6	81.3	113.7	139.3	145.9	179.7	157.0
R_3	203.6	201.4	267.1	214.0	191.8	163.0	242.2	216.1
Subsoil								
R_1	61.2	94.0	92.2	124.2	104.8	107.3	106.7	154.0
R_2	46.0	69.7	60.7	152.1	94.1	88.1	103.8	162.4
R_3	146.5	182.2	198.7	199.8	142.3	202.5	198.1	200.7

* i and ii denote replicates.

Table 42: Greenhouse Experiment I ; Sum of (a. N Uptake + mineral N lost by leaching + c. mineral N in soil).
Sampling 3 (7th. week of experiment).

water régime	FALLOW				PLANTED			
	no N		N		no N		N	
	* i	ii	i	ii	i	ii	i	ii
R_1	200.9	184.9	226.3	175.4	152.8	136.2	201.0	145.7
R_2	95.4	85.0	149.4	86.4	132.0	117.9	220.6	129.4
R_3	193.3	197.2	261.6	228.6	203.3	146.9	231.7	218.2
R_1	123.7	110.0	149.1	132.7	108.8	98.4	137.0	190.5
R_2	52.1	66.1	88.8	82.9	79.3	85.2	110.5	108.1
R_3	165.8	152.1	206.4	219.4	135.9	115.0	193.1	183.6

* i and ii denote replicates.

* Table 43 : Greenhouse Experiment I ; D.M. yield of plant.

(kg./ha.)

Time after start of experiment.	N treatment	Topsoil			Subsoil		
(weeks)		R_1	R_2	R_3	R_1	R_2	R_3
3	noN	1.47	1.75	1.75	0.72	0.70	0.80
	N	2.65	2.42	2.58	0.77	0.61	0.59
5	no N	3.32	5.04	2.88	1.55	1.09	0.80
	N	3.45	3.96	3.32	1.35	1.43	1.21
7	no N	3.01	3.53	2.25	1.71	1.23	1.32
	N	3.62	4.02	2.44	1.79	1.65	1.10

* Table : Greenhouse Experiment I ; %N in d.m. plant.

3	no N	4.02	3.49	3.06	4.99	4.52	3.12
	N	3.86	4.11	3.39	5.26	5.14	4.63
5	no N	2.68	1.86	2.30	3.48	3.79	2.71
	N	3.25	3.02	2.88	3.84	3.35	3.47
7	no N	3.34	2.60	2.88	4.14	3.53	2.48
	N	3.65	3.29	2.71	4.13	4.10	3.08

* Values are means of two replicates.

Table 44 :

Greenhouse Experiment II : Statistical analysis of data.

A. Mineral N in soil & Sum of mineral N + N uptake.

effect of ..	d.f.	NO_3-N	NH_4-N	NO_3+NH_4	(soil min. N+N uptake)
		stastistical significance of effect.			
B	3	ns	ns	ns	*
S	1	*	***	ns	ns
N	2	***	ns	***	***
P	1	***	*	***	***
S.N	2	ns	ns	ns	ns
S.P	1	ns	*	ns	ns
N.P	2	***	ns	***	*
S.N.P	2	ns	ns	ns	ns
Error	33				
Total	47				

B. D.M. Yield of plant & N Uptake.

		D.M. Yield			N Uptake			
		tops	roots	(tops + roots)	tops	roots	(tops+ roots)	ratio of tops: roots
B	3	ns	ns	ns	ns	ns	ns	ns
S	1	ns	ns	ns	ns	***	ns	ns
N	2	***	***	***	***	***	***	***
S.N	2	ns	ns	ns	ns	ns	ns	ns
Error	15							
Total								

(Table 44 cont.)

C.'Apparent recovery'of fertiliser N .

i. in plant tissues (i.e. tops+roots)				ii. overall recovery (i.e. in plant+soil)			
	d.f.	N_1	N_2		d.f.	N_1	N_2
B	3	**	ns	B	3	ns	ns
S	1	ns	ns	S	1	ns	ns
Error	3			P	1	**	***
Total	7			S.P	1	ns	ns
				Error	9		
				Total	15		

Effects :

B : Replicate (blockeffect).

S : Soil.

N : Nitrogen treatment.

P : Soil / Plant system.

Levels of statistical significance :

* 0.05 ; ** 0.01 ; *** 0.001 .

ns : Not statistically significant.

Table 45 : Greenhouse Experiment II : Contents of NO_3- & NH_4-N in soil (mg./pot)
(at end of experiment)
FALLOW

N Treatment	Ignited soil				Unignited soil			
	i	ii	iii	iv	i	ii	iii	iv
				NO_3-N				
no N	1.54	1.81	1.25	1.25	1.97	1.74	2.15	1.99
N_1	4.70	3.35	2.38	3.74	4.64	4.23	4.74	4.49
N_2	9.18	7.59	4.93	6.43	8.31	9.18	5.85	7.61
				NH_4-N				
no N	1.77	2.22	0.94	0.14	0.27	0.99	0.10	0.27
N_1	1.27	1.21	1.19	1.21	0.47	0.88	0.41	0.35
N_2	0.96	1.56	0.82	1.03	0.55	0.27	0.14	0.67
				(NO_3 + NH_4)N				
no N	3.31	4.03	2.19	1.39	2.24	2.73	2.25	2.26
N_1	5.97	4.56	3.57	4.95	5.11	5.11	5.15	4.84
N_2	10.14	9.15	5.75	7.46	8.86	9.45	5.99	8.28

i , ii , iii , & iv denote replicates.

Table 46 : Greenhouse Experiment II : contents of NO_3- & NH_4- N in soil (mg./pot)
(at end of experiment)

PLANTED

N Treatment	Ignited soil				Unignited soil			
	i	ii	iii	iv	i	ii	iii	iv
				NO_3-N				
no N	1.38	1.62	1.44	1.05	1.23	1.54	1.77	1.25
N_1	1.60	1.54	1.21	0.86	1.54	1.37	2.26	1.01
N_2	1.38	1.77	1.50	1.17	1.48	2.55	1.83	1.52
				NH_4-N				
no N	0.94	0.78	0.90	0.14	0.66	0.66	0.18	0.04
N_1	0.94	0.96	0.74	0.47	0.43	0.57	0.21	0.18
N_2	0.68	1.19	1.13	0.33	0.78	1.15	0.25	0.33
				(NO_3 + NH_4) N				
no N	2.32	2.40	2.34	1.19	1.89	2.20	1.95	1.29
N_1	2,54	2.50	1.95	1.33	1.97	1.94	2.47	1.19
N_2	2.06	2.96	2.63	1.50	2.26	3.70	2.08	1.85

i , ii , iii , & iv denote replicates.

Table 47 : Greenhouse Experiment II : N Uptake by plant.

(mg. /pot)

N Treatment	Ignited soil				Unignited soil			
	i	ii	iii	iv	i	ii	iii	iv
Tops								
no N	1.33	1.33	1.33	1.33	1.89	1.54	1.40	1.40
N_1	3.99	4.13	3.00	3.99	3.85	3.92	3.36	4.13
N_2	7.77	8.47	3.99	7.49	7.00	6.93	7.42	6.65
Roots								
no N	1.05	5.25	0.98	1.12	1.26	1.47	1.54	1.47
N_1	2.45	2.45	4.54	2.45	3.29	3.01	2.94	2.38
N_2	2.80	3.08	3.25	3.22	3.78	4.27	3.71	3.57
Tops + Roots								
no N	2.38	2.38	2.31	2.45	3.15	2.87	3.08	2.87
N_1	6.44	6.58	5.87	6.44	7.14	6.93	6.30	6.51
N_2	10.57	11.55	6.24	10.71	10.78	11.20	11.13	10.22

i , ii , iii , & iv denote replicates.

Table 48 : Greenhouse Experiment II

Apparent recovery of fertiliser N (% of amount applied)

N Treatment	Ignited soil				Unignited soil			
	i	ii	iii	iv	i	ii	iii	iv
In plant tissues (i.e. tops + roots)								
no N	0	0	0	0	0	0	0	0
N_1	82.9	85.7	72.7	81.4	81.4	82.9	65.7	74.3
N_2	83.6	93.6	40.1	84.3	77.9	85.0	82.1	75.0
In plant + soil (in planted soil)								
no N	0	0	0	0	0	0	0	0
N_1	87.1	87.8	28.4	84.3	83.1	77.3	76.5	72.2
N_2	81.0	99.3	43.1	87.4	81.6	100.3	83.6	80.7
In soil (in fallow soil)								
no N	0	0	0	0	0	0	0	0
N_1	54.3	10.6	28.4	72.9	58.6	48.6	59.4	52.7
N_2	69.7	52.1	36.4	62.8	67.4	68.7	38.3	61.5

i , ii , iii , & iv denote replicates.

Table 49: Greenhouse Experiment II : % of total N in soil (air-dry) at the end of experiment.

N Treatment	Ignited soil				Unignited soil			
	i	ii	iii	iv	i	ii	iii	iv
FALLOW								
no N	.050	.053	0.050	.087	.224	.230	.244	.230
N_1	.056	.044	.047	.044	.240	.241	.228	.230
N_2	.059	.056	.056	.056	.224	.240	.216	.202
PLANTED								
no N	.047	.081	.050	.064	.198	.216	.210	.202
N_1	.104	.050	.056	.053	.210	.092	.213	.221
N_2	.053	.100	.042	.050	.234	.234	.213	.198
no N								
N_1								
N_2								

i , ii , iii , & iv denote replicates.

Table 50 : Laboratory Experiment

Leaching loss of mineral N. mg/tube

(From soil tubes where no N was added)

A. loss in each leachate :-

Leachate	NO_3-N	NH_4-N	min. N	NO_3-N	NH_4-N	min.N
		*S			*L	
I	0.01	0.02	0.03	0.01	0.01	0.02
II	0.40	0.06	0.46	0.11	0.03	0.14
III	0.25	0.02	0.27	0.11	0.01	0.12
IV	0.38	0.07	0.45	0.33	0.04	0.37
V	0.16	0.02	0.18	0.16	0.03	0.19
VI	0.12	0.04	0.16	0.16	0.04	0.20
VII	0.10	0.04	0.14	0.09	0.02	0.11
VIII	0.07	0.01	0.08	0.09	0.01	0.10
IX	0.06	0.02	0.08	0.11	0.01	0.12
X	0.03	0.03	0.06	0.04	0.03	0.07

B. Cumulative loss :-

I	0.01	0.02	0.03	0.01	0.01	0.02
II	0.41	0.08	0.49	0.12	0.04	0.16
III	0.66	0.10	0.76	0.23	0.05	0.28
IV	1.04	0.17	1.21	0.56	0.09	0.65
V	1.20	0.19	1.39	0.72	0.12	0.84
VI	1.32	0.23	1.55	0.88	0.16	1.04
VII	1.42	0.27	1.69	0.97	0.18	1.15
VIII	1.49	0.28	1.77	1.06	0.19	1.25
IX	1.55	0.30	1.85	1.17	0.20	1.37
X	1.58	0.33	1.91	1.21	0.23	1.43

* S : Small aggregates .

L : Large " .

values are means of 2 replicates.

Table 51 : Laboratory Experiment,
Leaching loss of mineral N . mg/tube.
(From soil tubes where N was added)

A. Loss in each leachate :-

Leachate	NO_3-N	NH_4-N	min.N	NO_3-N	NH_4-N	min.N
		*S			*L	
I	2.00	0.04	2.04	1.58	0.07	1.65
II	4.38	0.09	4.47	4.13	0.09	4.22
III	3.03	0.13	3.16	2.74	0.05	2.79
IV	14.42	0.35	14.77	13.53	0.15	13.68
V	2.60	0.09	2.69	2.68	0.09	2.77
VI	2.00	0.10	2.10	3.11	0.08	3.19
VII	0.72	0.10	0.82	1.23	0.07	1.30
VIII	0.35	0.03	0.38	0.81	0.03	0.84
IX	0.27	0.06	0.33	0.83	0.03	0.86
X	0.08	0.06	0.14	0.19	0.06	0.25

B. Cumulative loss :-

I	2.00	0.04	2.04	1.58	0.07	1.65
II	6.38	0.13	6.51	5.71	0.16	5.87
III	9.41	0.26	9.67	8.45	0.21	8.66
IV	23.83	0.61	24.44	21.98	0.36	22.34
V	26.43	0.70	27.23	24.66	0.45	25.11
VI	28.43	0.80	29.23	27.77	0.53	28.30
VII	29.15	0.90	30.05	29.00	0.60	29.60
VIII	29.50	0.93	30.43	29.81	0.63	30.44
IX	29.77	0.99	30.76	30.64	0.66	31.30
X	29.85	1.05	30.90	30.83	0.72	31.55

* S : Small aggregates .
L : Large " .
Values are means of 2 replicates.

Table 52: Laboratory Experiment,
*Leaching loss of NO_3-N from sand . mg/tube.

Leachate	Loss in each leachate**		Cumulative loss	
	F	C	F	C
I	26.77	27.35	26.77	23.35
II	00.58	00.66	27.35	28.03
III	00.10	00.06	27.45	28.07
IV	00.24	00.18	27.69	28.25
V	00.12	00.09	27.81	28.34
VI	00.05	00.06	27.86	28.40
VII	00.02	00.02	27.88	28.42
VIII	00.01	00.02	27.89	28.44
IX	00.02	00.04	27.91	28.48
X	00.00	00.00	27.91	28.48

* : 1. Fertilizer NO_3-N was applied ; no control was carried out.

2. No NH_4-N was detected in leachates.

** : F : Fine sand .

C : Coarse sand .

Values are means of 2 replicates.